Issues Associated with Second-Source Procurement Decisions

J. L. Birkler, E. Dews, J. P. Large

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PREFACE

An important part of the process of improving defense acquisition analysis and management methods is the accumulation of experience of on-going or completed projects, especially if those projects involved unusual or innovative acquisition techniques. The research reported here reflects and shares RAND's considerable experience in evaluating the cost and quality implications of one innovative acquisition technique—second-source procurement strategy. Our experience has extended over a wide range of weapon system programs. However, because of the proprietary nature of the data or security classification associated with some of the systems analyzed (IIR Maverick, AMRAAM, B-2, Advanced Cruise Missile, and the like), reports describing the analytical methods used have had limited circulation. This report, prepared for general distribution, describes some of the advantages, disadvantages, and difficulties of various analytical techniques. The information should be useful to those who make decisions about the cost implications of introducing a second production source. In addition, this report is an attempt to respond to senior government officials, Congressional members, and their staffs who have encouraged us to document our findings in an unclassified and nonproprietary manner.

This report draws on research carried out in the Acquisition and Support Policy Program of RAND's National Security Research Division. Publication of the report was supported by RAND, using its own funds.

SUMMARY

The basic argument for competition in Department of Defense procurement is that it is believed to reduce the government's cost of purchasing goods and services. Nonetheless, in some cases (especially in the procurement of major systems) it may be actually less costly for the government to forgo competition and to rely on a single supplier. The DoD's program manager must determine whether competition is likely to result in savings or losses for the government; if competition is indicated, he must then decide on what specific form it should take. This report focuses on one of the DoD's strategies for establishing competitive production sources: "second-source" procurement, in which two firms produce a single design. The leader is usually the system designer and developer, and the follower, a second production source most often established at government expense. This is usually referred to as a leader-follower strategy.

Such an arrangement does not meet the requirements of traditional economic theory for the forces of competition to operate with full effectiveness. Only one buyer and only two sellers exist; demand is inelastic but uncertain; the buyers' budgetary priorities can change over time and are often independent of a firm's contractual performance and the nature of the product; entry and exit of firms may be slow and costly; there are large capital requirements that are often funded by the buyer; both firms produce the same design; and, finally, the producer with the higher price is guaranteed a share of each buy. Second-source procurement is thus an artificial form of competition, and one should not expect to obtain from it all the benefits that accrue as a result of traditional price competition involving many buyers and sellers.

We do not question the value of competition as a means of inducing a firm to reduce prices. In some cases of second-sourcing, however, the splitting of production between two firms will result in a higher cost to the government. The incremental nonrecurring costs for a complete technical data package for the second producer, for additional tooling and test equipment, and for qualification testing can run into the tens or hundreds of millions of dollars. There is also the incremental cost of one or more "educational buys"—purchases to give the second source an opportunity to learn how to manufacture the product in accordance with a technical data package provided by the initial source. There are also potential increases in recurring costs from loss of learning-curve benefits and lower production rates. Consequently, it is not self-evident that second-sourcing will produce savings for the government in every major procurement.

Retrospective studies of second-source procurement programs have not been conclusive, partly because the answers depend heavily on the analytical methods used. A 1981 RAND study showed how an analysis of prices paid for the Shillelagh missile could produce estimates ranging from a procurement cost savings of 79 percent to a loss of 14 percent, depending on the researcher's choice of procedures.[1] Some uncertainty is inevitable, because the various methods used for measuring savings are unavoidably judgmental. In particular, if two sources are used, one cannot know the cost that would have been incurred with a single source only. That cost must be *estimated* and compared with the *actual* cost incurred through second-source procurement.

This report describes five methods of estimating single-source cost. With each method we estimated the hypothetical single-source cost for four air-to-air missile programs (AIM-7F, -7M, -9L, -9M). In none of these do all five analytical methods indicate that savings accrued to the government. However, three of the five methods show savings for two procurements (AIM-7F and AIM-9L), and four show a loss for one procurement (the AIM-7M).

The effect of competition is seen most clearly in changes in the unit price of a product. It is an article of faith in many quarters that unit price will decrease in the first competitive lot produced, and the slope of the learning curve will steepen. This is referred to as the shift-and-rotation hypothesis—the level of the learning curve shifts downward and the curve rotates downward. This hypothesis is often relied on for predictive purposes, usually at the unit-price level but sometimes at the producer's functional-cost level (factory labor, materials, etc.). We tested the hypothesis at both levels—that is, for the *price* paid by the government and the functional *cost* incurred by the producer.

An examination of functional costs on the four second-source programs revealed no consistent characteristics or patterns that would enable one to identify when competition began or which lots were procured in a competitive environment. Where the learning curve does rotate, many different factors appear to be influencing cost, such as increased production rate, engineering design stabilization, workforce stabilization, etc. For material cost, some evidence of a downward shift appears but little to support the concept of a downward rotation. For factory labor, a downward shift did not occur when competition began, and rotation occurred in only two of the four programs. Engineering and manufacturing support labor showed the largest percentage cost reductions at the start of competition, and these are the areas in which

[1]K. A. Archibald et al., *Factors Affecting the Use of Competition in Weapon System Acquisition*, R-2706-DR&E, February 1981.

a contractor has the greatest opportunity for reductions in labor manhours.

The effects of competition are more likely to be seen at the unit-price level, because at that level changes in hourly labor costs, overhead rates, and profits are included as well as changes in labor hours and material costs; and in fact our analysis gives modest support to the concept of shift and rotation where unit price is concerned. Depending on the procedure used for projecting a single-source curve, both shift and rotation occurred in three of the five unit-price cases examined. *The range of values is too wide, however, to support the notion that the amount of shift and rotation can be predicted with any confidence.* Moreover, the data do not show a fixed shift-and-rotation pattern. Major price reductions may occur before formal competition or in the first, second, or third competitive lot.

A sample of eight Navy programs examined by the Naval Center for Cost Analysis (NCA) showed a somewhat different pattern of behavior between leader and follower. Downward shifts in price ranging from 6 to 36 percent were observed in those eight programs with the learning-curve slope generally unaffected.

The NCA study reinforces the concept that second-sourcing does affect the unit-price learning curve.[2] In every case we examined, second-sourcing produced a shift, a rotation, or both. That does not mean that second-sourcing would produce savings, if it was adopted in all cases. Moreover, one can examine only those cases for which single-sourcing was rejected as being the more expensive alternative. Presumably, second-sourcing was chosen because it appeared to offer a financial advantage; hence it is not surprising when after-the-fact investigation confirms the earlier analysis.

Dollar savings are not the only reason for bringing a second producer into a program. National security considerations may dictate having two producers for a system or subsystem. Improved quality assurance is often cited as a reason for second-sourcing. In some instances the underlying reason has been a profound dissatisfaction with the initial contractor, which may be a good developer but not an efficient producer. The nature of defense procurement is such that once a contractor is chosen to develop a major new system, the responsible military service is locked into a relationship with that contractor that could last 20 years or more. Bringing a second company into a program is an effective way to encourage greater cooperation from the initial firm.

[2]Results of Navy Competition, Assistant Secretary of the Navy (Shipbuilding and Logistics), January 3, 1989 (unpublished).

Comparisons of single-sourcing and second-sourcing for new production programs usually concentrate on the dollar value of the savings to be achieved. We believe that there is no reliable method for predicting that value; the essential cost question is not the amount to be saved, but whether the introduction of a second source will generate some financial benefits or penalties. One way to make that determination is on the basis of a breakeven analysis that deduces the magnitude of pure savings needed to compensate for the cost to the government of introducing a second source.[3] The deduced value is compared with the estimated single-source cost over the same quantity interval to obtain a figure of merit called the "undercut percentage," which is then compared with actual historical values to assess its likelihood of being achieved. For example, an undercut value of 10 percent or less is said to imply a reasonable expectation of savings, 30 percent or more implies that savings are unlikely to be achieved.

The Cost Analysis Improvement Group (CAIG) in the Office of the Secretary of Defense, which reviews Service estimates, has used this method on several programs, and the results have been considered useful. The uncertainties inherent in other methods, however, have not been eliminated. It is still necessary to extrapolate a single-source learning curve from early lot data, to assume shift and rotation values, and to rely on the message conveyed by undercut values. It seems to us that the results of this method are equivocal. Its greatest utility is probably in programs for which the undercut percentage is very low or very high, say under 10 percent or over 30 percent.

A more straightforward use of the breakeven method is to calculate the production quantity required for the cost of second-source procurement to equal that of single-source procurement. Breakeven quantity can be calculated for a variety of assumptions regarding single-source costs, incremental investment for second-sourcing, precompetition quantity, discount rate, etc. and displayed in a series of curves. This method does not eliminate any of the uncertainties inherent in predicting the effect of competition, but it has the considerable advantage of showing explicitly how the necessary assumptions affect the results.

The Tomahawk cruise missile project illustrates the use of second-sourcing to reduce program cost and the risk of interrupted or unsatisfactory production and to improve missile reliability. During development, General Dynamics' Convair Division (GD/C) had the responsibility for the airframe and for flight vehicle integration, and McDonnell-Douglas (MDAC) had responsibility for the guidance systems. The Joint Cruise Missile Project (JCMPO) believed that GD/C

[3]This method is described in Milton A. Margolis, Raymond G. Bonesteele, and James L. Wilson, "A Method for Analyzing Competitive, Dual Source Production Programs," a paper presented at the 19th Annual DoD Cost Analysis Symposium, September 1985.

costs were too high and that quality assurance problems were not receiving sufficient attention. The JCMPO succeeded in negotiating contracts with both contractors to exchange technology so that each could produce All-Up Rounds (AURs), a flightworthy missile in a launch-compatible canister or capsule.

Initially, the JCMPO believed that competition could produce savings in excess of $500 million excluding investment associated with capitalization of tooling and test equipment. Estimated savings depend on the estimated cost of single-source procurement, the way in which data are adjusted to achieve year-to-year comparability, and estimates of the incremental nonrecurring cost of second-sourcing. The JCMPO, GD/C, and the NCA each approached the estimating problem differently. Using figures from those three organizations, we calculated the breakeven quantity to illustrate how sensitive that quantity is to the assumptions embodied in estimates of savings. The JCMPO figures indicate that breakeven occurred at about 130 units—even before formal competition began—primarily because nonrecurring costs for single-source procurement were incurred early in the program but began later for second-sourcing and were spread out over a longer period. The GD/C study implies breakeven in the second year of competition at 1400 units, and the NCA study indicates the fourth year at 2000 units. Despite those differences, the three organizations agree that second-sourcing will produce savings. Estimates range from $400 million to $1.25 billion (undiscounted) for a buy of 4500 missiles.

According to the JCMPO, the primary reason for second-sourcing the Tomahawk AUR was not to reduce cost but to improve quality assurance procedures. It is difficult to establish a cause-and-effect relationship between second-sourcing and improved quality in a product. Quality improves over time in all programs as more tests are conducted and problems isolated. In the case of Tomahawk, the JCMPO asserted that the basic problem was GD/C's disinclination to take the strenuous action required to correct engineering and manufacturing quality control problems. Consequently, the JCMPO took two parallel actions. The first was to initiate a dual-source effort; the second was to issue a series of corrective action directives. Both contributed to a change in corporate attitude, but it would be mere speculation to claim that one was more important than the other.

Whatever the real reason for second-sourcing may be, lower cost is the usual justification. Savings are not inevitable, however. The issue is whether the planned production quantity is sufficient that the savings in recurring costs will offset the incremental startup costs of second-sourcing. The Tomahawk AUR program provides a good example of the specific factors to look for in choosing candidates for

second-source procurement. The cost of entry for a second producer was low; the original firm projected a fairly flat learning curve for single-source production; annual production quantities were large enough to absorb the fixed and semi-fixed costs without distorting AUR unit costs unduly; and the total planned production quantity was large enough that breakeven at some point was virtually guaranteed.

A variety of analytical techniques may be useful in evaluating potential savings from second-sourcing—e.g., estimating dollar savings directly, determining the breakeven quantity, solving for the shift and/or rotation required to break even at the planned quantity. We are not arguing for any particular method here; we are concerned only that analysts use all the information available to them, including historical data for a given class of equipment, and do not rely on the dogma of "competition" to provide an answer.

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I. INTRODUCTION

Competition in weapon system acquisition is widely advocated in policy statements and regulations issued by the Congress, the Office of Management and Budget, the Department of Defense, and the military services. In recent years Congress has specified that funds cannot be used to initiate Full Scale Engineering Development (FSED) of any major defense acquisition program until the Secretary of Defense provides to the Committees on Appropriations of both the House and Senate either (1) a certification that the system or subsystem being developed will not be procured in quantities that are sufficient to warrant development of two or more production sources, or (2) a plan for the development of two or more sources for the production of the system or subsystem being developed.

This requirement stems primarily from the conviction that competition during the production phase will drive the price of a system or subsystem down and thus help to reduce overall procurement cost to the government. There may be other benefits from having more than one producer that are not directly measurable in procurement dollars—e.g., (1) providing a surge capability should the service need to expand production quickly; (2) reducing risk of late or faulty deliveries due to production problems, labor disputes, or acts of nature; and (3) maintaining the country's technical and production expertise for a particular weapon system. It has been suggested that second-sourcing can have a salutary effect on product quality and program Quality; the capital Q is intended to imply quality of design, producibility, schedule adherence, and responsiveness to the buyer, not simply quality assurance.[1] But the basic argument for competition in DoD procurement is that it reduces the cost to the government of new military equipment.

Competition in system *design* is standard procedure in DoD and has been for many years. It may or may not produce savings, but that is not its goal. Its purpose is "to select the best technical approach within affordable costs." Competition among contractors in the *production* of major military systems is much less common, primarily because small production quantities make it uneconomic to have more than one producer. The program manager must decide when

[1]Letter from Col. Arnold D. Michalke, USAF, Acting Director, Strategic Aeronautical and Theater Nuclear Systems, Office of the Director of Defense Research and Engineering, 18 April 1990.

competition is warranted and what form it should take—form, fit and function; second-source procurement; licensing; contractor teaming; etc.[2] Each strategy may offer some possibility for savings, but the outcome depends on specific project circumstances.

This report focuses on just one of the various strategies for establishing competitive production sources: second-source procurement, in which a single design is produced by two firms—the initial source, usually the system designer and developer, and a second source qualified for production largely at government expense. This strategy, often known as leader-follower procurement, has been adopted in many guided missile programs where the production quantity has been judged large enough to justify the incremental cost of establishing the follower as a second source. After the follower has been qualified (has produced enough units to demonstrate the required capability), the two firms compete to determine which will produce the larger share of each successive procurement of the item.

Such an arrangement does not meet the requirements of economic theory for the forces of competition to operate freely. Only one buyer and two sellers exist; demand is inelastic; the buyer's budgetary priorities often change and are independent of a firm's performance; entry and exit of firms may be slow and costly; large capital requirements may be mainly or entirely funded by the buyer; and, finally, the producer with the higher price is guaranteed a share of some or all of the successive buys. We point out these differences to illustrate that dual-source procurement is a synthetic competition rather than the real thing. One should not expect to obtain all the benefits that accrue as a result of genuine price competition involving many buyers and many sellers.

The value of competition in our society is so much taken for granted that defense procurement officials are often criticized for not relying more frequently on head-to-head competition in awarding production contracts for major defense systems. As stated above, however, the special nature of the defense market limits the opportunities for free and unfettered competition. Section II describes the characteristics of that special nature and provides background information so that the issue of second-source procurement can be viewed in perspective.

Splitting production between two contractors may result in either savings or losses. The problem for the DoD is that despite numerous studies, when a decision about second-sourcing must be made there is still no foolproof way of predicting whether the outcome will be a

[2]L. A. Kratz, J. W. Drinnon, and J. R. Hiller, *Establishing Competitive Production Sources*, ANADAC, Inc., Arlington, Virginia, August 1984, describes each of these alternatives along with their advantages and disadvantages.

savings or a loss. Nor, as pointed out in Sec. III, do retrospective studies of second-sourcing agree as to whether savings or losses have been achieved, much less agree as to their precise magnitude. Various methods have been developed over the past 25 years, none completely satisfactory. This report offers a critical review of such methods as a means of helping program managers make a more informed decision about the use of second-sourcing.

A problem common to all methods is the need to estimate what single-source costs to the government would have been had a second contractor not been brought into a program.[3] Section IV describes five methods of projecting *single-source* costs and shows how the choice of method affects the estimate of savings. Section V presents methods of estimating *second-source* costs, and Section VI discusses the "breakeven" method for deciding whether single-source or second-source procurement would be more advantageous. In Section VII we present a short case history of the Tomahawk program to illustrate some of the problems and concepts discussed in previous sections. We also look briefly at the possible effect of second-sourcing on product quality in the Tomahawk program. Section VIII presents our conclusions.

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[3]Following common practice in defense acquisition, "cost" as used here generally refers to the cost to the government of procuring an item or a number of items. The context should make it clear when the text refers to the contractor's cost of production.

II. COMPETITION IN MAJOR DEFENSE ACQUISITIONS

Major defense acquisitions that have many characteristics are quite different from those typical of commercial transactions. These special characteristics, taken as a whole, create a formidable set of difficulties that must be overcome if the benefits hoped for by the proponents of price competition in defense procurement are to be realized. In major defense acquisitions the relationship between buyer and producer is different from that traditionally assumed in the idealized model of the perfect market. It is also different from that found in the imperfect but reasonably effective price-competitive markets that most people are familiar with and that may be considered the norm in American industry. Unless these differences are taken into account, too much may be expected from attempts to increase the use of price competition in defense purchases.

Major systems constitute only a part—but a large part—of DoD expenditures on equipment and supplies. DoD's purchase of fuel and many other items for which there are active, nondefense markets is an altogether different matter. For such items price competition is usually vigorous and effective, and we need not be concerned with them here.

When price competition is effective, the competing producers have strong incentives to lower their production costs by striving for efficiency in the use of labor, capital equipment, and other resources. At the same time the buyer can usually be assured of a firm price that reflects good production efficiency and includes little more than a normal profit without substantial monopoly markups.

It is sometimes suggested that similar benefits in production efficiency and price can be achieved for major acquisitions simply by opening production contracts to competitive bidding by prime contractors. But this assumes a kind of market that does not really exist. It assumes, for example, that (1) the major system to be produced has already been fully developed and the design stabilized, (2) several prime contractors are fully qualified to produce the desired system or an already-developed close substitute, (3) the buyer's future-year funding for production contracts is stable and predictable, and (4) the prime contractors are willing to offer firm fixed-price bids, with fixed-price options for a long series of future-year buys so the buyer won't have to make future-year purchases in a sole-source environment.

To the extent that price competition is effective in major system acquisitions it is largely attributable to specific efforts undertaken by the government buyer, often at considerable expense to the government, to change the nature of the market and so create an environment more favorable for price competition.[1] For this and other purposes, acquisition policymakers and program managers have developed competition-enhancing strategies for use at one stage or another during the acquisition process. The logic and timing of these strategies depend on the characteristics of the major-acquisition marketplace. Here we focus on the second-sourcing strategy.

DEFENSE ACQUISITION CONTRASTED WITH IDEAL COMPETITION

The special nature of the environment for competition in major system acquisitions can be illustrated by comparing it with the conditions usually called for in the idealized model of the perfectly competitive market. Those conditions are summarized in Table 1. The comparison indicates why there are inherent difficulties in introducing effective price competition into major defense acquisitions. It also provides a key to understanding the variety of competition-enhancing arrangements that have been developed.

DEFENSE ACQUISITION: A MULTI-STEP PROCESS

The Conventional Description: Three Milestones

The conventional view of the defense system acquisition process is that it consists of a small number of distinct steps or phases (milestones) defined by major decisions made in the Office of the Secretary of Defense (OSD). From a certain policy standpoint this is so, and the milestones are convenient for some management and descriptive purposes, but they do not reveal the truly complex nature of the relationship between buyer and contractor.

As the process is usually described, there are three steps or phases in the buyer-contractor relationship. Beginning with OSD acquisition

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[1]For convenience the sales relationship between major-system buyer and producer(s) is referred to here as a "market," although to many economists that is an inappropriate use of the term. In a study that has become a classic, Peck and Shearer argue that "a market system in its entirety" does not exist and "can never exist" in major defense acquisitions. Merton J. Peck and Frederic M. Scherer, *The Weapons Acquisition Process: An Economic Analysis*, The Harvard Graduate School of Business Administration, Boston, 1962, p. 57.

Table 1

MARKET CHARACTERISTICS VERSUS TYPICAL CHARACTERISTICS OF THE MARKET FOR PRODUCTION OF MAJOR DEFENSE SYSTEMS

a = Perfect Market
b = Defense Acquisition

1a. Many buyers and producers, none dominant; each buyer has a choice of many producers. Price (a firm fixed price) is determined by the "hidden hand" of the market.

1b. Only one buyer and usually only one producer—the prime contractor who developed the system. Production prices (seldom truly firm fixed prices) are determined by a long series of successive negotiations in a sole-source environment.

2a. The product is an existing, standardized item, the same for each producer—it is "homogeneous," and its characteristics are stable over time.

2b. The product is a newly developed item, usually without close substitutes, and with a design that may not be fixed until after production begins, and often not even then.

3a. Competition focuses on price alone.

3b. Price is by no means the dominant consideration in selecting the producer. The buyer is concerned with product quality (especially performance), with delivery schedule, and with other nonprice factors.

4a. No producer has an advantage in production technology or economies of scale.

4b. Production technology is dynamic and may differ among prime contractors and their subcontractors. Economies of scale influence producer costs ("learning-curve" effects can be important).

5a. The market is easy for new producers to enter.

5b. New prime contractors seldom enter the defense sector; entrance is inhibited by the high capital investment required, the proprietary rights of others, and the administrative and contractual burdens of a highly regulated industry.

6a. The market is characterized by perfect intelligence and absence of uncertainty. Information about product price, standards of quality, number of items purchased, and delivery schedule is freely available to all concerned.

6b. Uncertainty is a dominant and largely unavoidable feature of a major system acquisition—for example about design changes after production begins, the stability of program funding and production rate, the total number of items to be produced, the possibility of emergency or surge demand, and the effect of the acquisition on the defense industrial base.

7a. Buying the product is a simple, quickly completed one-step transaction between the buyer and the producer, independent of other purchases from the same or other producers.

7b. Acquiring a major system is a prolonged, complex, multi-step process, requiring many years—even decades—for completion and involving scores of successive, usually interdependent contract negotiations between the buyer and the producer.

Milestone I, these phases are Demonstration-Validation (Dem-Val); Full-Scale Development (FSD) or, as it is sometimes referred to, Full-Scale Engineering Development (FSED); and Production. We omit from this description any special arrangements to foster competition, other than the usual design rivalry following Milestone I. Before that milestone, in the Concept Exploration phase, a statement of need has been agreed upon, alternative system concepts have been considered, and a preferred concept has been identified in rather general terms. Then, after a go-ahead decision has been made at Milestone I, the Dem-Val phase begins, the first of two steps in system development. In Dem-Val, the contractors put forward design approaches and assess their feasibility. Prototypes may be built and compared (fly before buy); preliminary estimates are made of system performance, schedule, and price; and the tradeoffs among them are considered. But the emphasis is on the feasibility of system design and the capabilities it promises. Contractor rivalry tends to focus on quality, or quality and schedule, more than on price.

The next step, FSD, begins with a go-ahead decision at Milestone II. The service requests proposals from several contractors, almost always the few prime contractors that participated in the Dem-Val phase. In these proposals the rival designs and their estimated capabilities can be described in much more specific detail. In most cases, because of the high cost of FSD—10 to 20 percent of total acquisition cost—only a single prime is chosen. The task of the FSD contractor(s) is to bring development to a point where the transition to production can begin, and FSD contracts usually call for some initial output at low production rates.

Price receives substantially more attention in the selection of the FSD contractor(s) than in earlier phases; for example, design-to-production-price goals may have been established in the request for proposals. But it is recognized that the contractor's cost estimates for FSD and production are still subject to revision, typically upward. The choice of the prime contractor(s) for FSD is normally weighted in favor of expected system quality with price as an important but still secondary consideration.

The third step in this conventional description of the buyer-contractor relationship concerns production. A favorable Milestone III-A decision authorizes the beginning of low-rate production of the system. A production contract is then negotiated; and if there has been only a single prime contractor in the FSD phase, the negotiation is conducted in a sole-source environment. Later, a favorable Milestone III-B decision authorizes full-rate production.

The Reality: Scores of Procurement Steps Extending over Decades

This three-step description of buyer-producer relationships is much more complicated than the one-step transaction postulated in the perfect-market model, but the reality is even more complex. The complexity of the buyer-producer relationship is reflected in the large number of contract negotiations that take place between the buyer and the prime contractor during the course of the acquisition process. This multiplicity of negotiations is the result of several interrelated factors: many sources of continuing uncertainty during acquisition, very long program duration, a product that changes over time with development typically continuing well into the production phase, and a widespread institutional preference for frequent sequential decisions having only short-term validity.

Program duration varies substantially from system to system, but the averages in Table 2 should suffice to demonstrate that a major acquisition is typically an extremely long process. From the beginning of the Dem-Val phase to the completion of the formal production phase the average time required is well over 20 years. Moreover, if the practice of stretching out production by reducing production rates continues in the future (as may well happen in an era of declining defense budgets), the time required for the typical acquisition may take even longer. Finally, in the post-production period, spare parts produced by the prime contractors may be required for many additional years.

The story does not end when system production is completed some 20 years or more after the beginning of Dem-Val. After the last unit is produced, the system will continue to be operational for many years and will require continuing production of spare parts. It is also likely that the system will be progressively upgraded by retrofitting with improved subsystems, a process that sometimes also requires expensive changes in the configuration of the basic platform or vehicle. For some aircraft this post-production period may itself exceed 20 years, especially now because of the diminished number of new program starts and the resulting extension of operational lifetimes well beyond the planned number of years in service.[2]

For a single major acquisition, the contractual relationship between the government and the prime may continue over a period of 30 years or more—beginning with (or even before) Dem-Val and ending with the

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[2]See Michael Rich and Edmund Dews, *Improving the Military Acquisition Process, Lessons From RAND Research*, The RAND Corporation, R-3373-AF/RC, February 1986, pp. 23–24. This report specifically warned against *mandated* competition for all prime contract awards (p. x).

Table 2

DURATION OF ACQUISITION ACTIVITIES

Activity	Duration (years)
Demonstration-validation[a]	3-1/2
Full-scale development[a]	4-1/2
Production[b]	16
Total average duration (through production)	24
Post-production period	Many additional

[a]Average of a large sample of Air Force and Navy aircraft and missile systems with acquisition beginning after 1960; see M. B. Rothman, *Weapon System Acquisition Milestones: A Data Base*, The RAND Corporation, N-2599-ACQ, October 1987, Figs. 2 and 3. There is, of course, a large variation from system to system as Rothman shows.

[b]See Congressional Budget Office, *Effects of Weapons Procurement Stretch-outs on Costs and Schedules*, Washington, D.C., November 1987, pp. 23–24, especially the data in Table 5, exclusive of the two armored fighting vehicles listed there. The projected total production time for 24 aircraft and missile systems averages well over 16 years. This is the result when the years already in production are summed together with the future years required to complete the *programmed* buys at the FY 1989 rate. The actual duration of the production phase may be even longer than was programmed for systems not terminated before completion of the total planned buy.

last post-production upgrade or spare-parts purchase handled by the prime contractor. This decades-long buyer-contractor relationship in major system acquisitions is one reason for the multiplicity of contract negotiations and renegotiations that occur between the two parties. Another reason is the widespread institutional preference on the buyer's side for short-term, sequential decisionmaking. The Congress has preferred to exercise procurement control through *annual* appropriations, even with biennial defense budgets and for procurements for which multi-year contracts have been approved. Thus most major-system contracts (or contract amendments) are negotiated for a single year's buy. Even if the Congress adapts "milestone authorizations"

and biennial appropriations along the lines recommended by the Packard Commission and others, the long buyer-seller relationship would still have to respond to perhaps 10 or 15 Appropriations Acts, with many (probably most) of these requiring new contract negotiations for quantity and price.

This institutional preference for short-term, sequential decisionmaking is by no means restricted to the Congress. Because of uncertainties about the threat and, especially, uncertainties about future-year funding levels, budget allocation decisions, and the timing of new starts, both OSD and the individual services have generally preferred to retain programming flexibility by avoiding long-term contractual commitments.[3]

Contract administrators and auditors prefer short commitments for administrative convenience, so that they can close out contract files in a few years and avoid long and complex audit trails. Compared with longer-duration contracts, short-term contracts may also have financial benefits for the government, for example, by shortening the period before contractor profits are calculated and taxes become payable.

During FSD and the early years of production, program managers want the contractual flexibility to make desirable design tradeoffs, to fund major design changes, and to approve at least some of the many engineering change orders that usually are proposed at this time. These actions require frequent contract renegotiation or the negotiation of contract amendments. Other contract negotiations involve such things as long-lead-time procurements, additional test items and test support, initial and other spares, data rights, special studies, foreign assistance, new subsystems, and retrofits. The result is that the contractual relationship between the buyer and the seller is neither the one-step transaction of the perfectly competitive market nor the three-step transaction implied by the OSD milestone decisions. Although there may be only a limited number of basic agreements or master contracts, perhaps as few as three or four, *the number of separately negotiated supplemental agreements or special purpose contracts relating to a given system amounts to many scores or even many hundreds during the long course of acquisition and post-production activities.*

Most of these negotiations involve the pricing or repricing of goods or services, and for most major acquisitions (even those for which the buyer has adopted one of the strategies for enhancing prime-contractor competition), many of these negotiations are conducted in a sole-source environment. This helps to explain two frequently made observations:

[3]Some members of the services have argued for greater use of multiyear contracts as a means of locking in stable funding for favored acquisitions, even at the cost of decreasing the stability of other acquisitions.

(1) that system acquisition is essentially a cost-based activity in which the contractor's total profits are positively correlated with the contractor's costs, and (2) that a contractor who "buys in" or otherwise loses money in the Dem-Val and FSD phases of acquisition will have many opportunities to "get well" later if he can secure production and post-production contracts.

What was said earlier about the near-continuous nature of system development and modification during the acquisition and post-production periods thus applies with almost equal force to the frequency of contract negotiations. Continuing product improvement generates continuing contract negotiations. In those circumstances the relationship between the buyer and a producer is almost never simply an arm's-length, legalistic contractual relationship, although that is often held out as the ideal.

Program managers are concerned with acquisition price, of course, but they also place a high value on a contractor relationship characterized by mutual confidence, close cooperation, and responsiveness and reliability. In many of the most successful acquisitions the relationship between the program manager and the contractor can be described as essentially symbiotic. The tension between this cooperative view of the buyer-contractor relationship and the near-adversarial contractual view adds further complexity to the problem of achieving effective price competition in the acquisition of major systems.

PRE-PRODUCTION RIVALRY AND SECOND-SOURCE COMPETITION

Table 1 described the wide divergence between the actual buyer-producer relationship in major-system acquisitions and the buyer-seller relationship as idealized in the paradigm of the perfect market. The ghost of the idealized market still haunts much popular discussion of methods for improving defense acquisition, and it is important to lay that apparition to rest. Further, the details of this divergence help in understanding the difficulties the government's buyer faces during the production phase of acquisition if he attempts to create some kind of proxy for a market in what would otherwise be a sole-source environment.

The relevant question is not whether one can rely on price competition among major-system producers to guarantee an ideal outcome but whether the limited kinds of competition that the buyer is able to create will produce better outcomes than would be expected in their absence. The focus should be on the marginal effect of the buyer's

introduction of a market substitute, second-sourcing being the substitute considered here.

The marginal effect of second-source price competition depends upon many factors, some of which are difficult for the buyer to control or even assess with confidence, because they are internal and specific to each firm. Among such internal factors are the firms' current and future capacity utilization, their long-term business strategies, their relative efficiency as producers, and the degree to which (however informally) they may collude to influence prices. Thus, the benefits to be derived from a second-sourcing strategy depend in part on the characteristics of the two sources, and therefore to some degree on the criteria by which the buyer chooses the two sources.

The choice of the lead producer occurs in the pre-production phases of acquisition, usually in Dem-Val but very occasionally in FSD. In Dem-Val, where the cost to the government of funding each rival contractor is often rather modest, there may be several competing firms, three or four or even more, but never the large number assumed in the competitive ideal.[4] In FSD, where the cost of funding a developer is normally a substantial part of total acquisition cost, it is uncommon for the government to fund more than one contractor and vanishingly rare to fund more than two. In a typical major-system acquisition, a single contractor is chosen at the end of Dem-Val to develop the system *and produce it.*[5] If a second-sourcing strategy is then adopted in the production phase, the initial producer is the contractor chosen by the buyer before full-rate production experience with the system, and, in most cases, even before full-scale development.

The choice of the lead producer is therefore based primarily on criteria other than production price. Competition among contractors in Dem-Val is thus more accurately referred to as design rivalry. In source selection after the completion of Dem-Val, it is the *quality* of the rival designs, especially their expected or promised performance parameters, that the buyer is most concerned with. True, other criteria are formally taken into account, among them system producibility and maintainability, program schedule, contractor performance in earlier programs, and, of course, price. But system performance characteris-

[4]If the buyer expects the rival contractors to pay a substantial part of their own costs during Dem-Val, it would be counterproductive to increase the number of contractors to the point where each contractor perceives its chances of winning as small.

[5]For major-system acquisitions, it is generally taken for granted that the developer should be the initial producer because of system complexity, the need for the developer to be available for further development or system modification, and the advantage gained by the developer through even a modest amount of production experience.

tics usually dominate in source selection at this time.[6] In any case, production price must be regarded as a highly uncertain estimate at the end of Dem-Val before complete prototypes are available and long before any real production experience has been acquired.[7]

If success in Dem-Val design rivalry correlated highly with efficiency in production, this design-quality method of choosing the producer might be reasonably satisfactory, even in a sole-source environment, given an honest contractor held to an appropriate auditing of costs. Production price would presumably be "cost plus," but the producer would be a low-cost producer.

The contractors that do best at design may not also do best at production. We know of no rigorous examination of this question, but anecdotal evidence is at least sufficient to create doubts.[8] At a minimum it seems fair to say that a decision made on the basis of preproduction design rivalry sometimes leads to the selection of contractors that are inefficient producers. When this is so, the possibility of achieving savings through second-sourcing should be enhanced, because it would provide the opportunity to procure at least part of the total buy from a more efficient producer. Second-sourcing in the production phase would thus be a response to imperfections in the "market relating to production price" earlier in the acquisition process.

Savings to the buyer through lower prices attributable to second-sourcing may thus reflect: (1) the replacement, for part of the buy, of a high-cost first-source producer by a lower cost second-source producer; and (2) the incentives provided by the limited (duopolistic) price competition between the two producers such that, during the course of this competition, either or both of the producers may (but not necessarily will) (a) strive for greater production efficiency, or (b) structure their bids with lowered profit margins, or both. These incentives, of course, may affect producer behavior even before second-sourcing begins, in expectation of its implementation.

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[6]Attempts to mandate a "design-to-cost" approach have had very limited success at best.

[7]The great uncertainty about production price is one of the reasons why effective competitive bidding among the Dem-Val rivals has proved to be impracticable for a post-Dem-Val "total package" contract embracing both FSD and system production. From the contractor's point of view, the uncertainties are too great to risk a firm fixed price bid for so costly a total package. From the government buyer's point of view, several experiments with total package procurement suggest that it is likely to be both unenforceable and plagued by litigation.

[8]These doubts have caused some knowledgeable students of defense acquisition (notably B. H. Klein at RAND as early as the 1960s), to suggest that it might be desirable for design and development to be separated, functionally and contractually, from production. Some firms, that is, would specialize in design and development, others in production.

III. SECOND-SOURCE COMPETITION

Second-source competition has been studied and restudied, and the consensus of those studies is that this type of procurement has saved the government money in many acquisition programs. In some cases, however, splitting production between two contractors will result in a higher cost to the government. The problem for the DoD is to decide whether single- or dual-source procurement is the more effective approach in any given acquisition program and to make that decision before production is well underway.

We do not question the value of competition as a means of inducing a firm to reduce prices. When competition or the threat of competition is perceived as real, a firm can act in a number of ways to cut costs and price. Managers often assign their best people to a competitive program, allocate corporate capital for equipment, and fund value-engineering studies (rather than expecting the customer to fund them). A company can transfer production from an area of high labor costs such as California or Massachusetts to another part of the country where labor costs are lower. For example, the *Los Angeles Times* reported in November 1989 that General Dynamics had built an assembly plant for missile parts on a Navajo reservation in New Mexico where Navajo workers would earn about $5.50 per hour compared with a rate of more than $9.00 in California. Or a firm may choose to transfer production out of the United States to reduce costs. In 1989 the Lockheed Corporation conducted a competition to select a subcontractor to assemble the outer wing sections of the Navy's P-7A antisubmarine patrol aircraft. Daewoo Heavy Industries of South Korea in competition against Avco Aerostructures and Canadair submitted the winning bid.

Management can take measures to substitute capital for labor, accelerate cost-reduction schemes, and seek out alternative vendors. A firm may be able to operate at an economical rate by producing enough parts in a few months to satisfy the contractual requirement for an entire year, then assign the workers to other tasks for the remainder of the year. Also, a company is usually able to reduce the number of engineering and manufacturing support personnel assigned to a program. Noncompetitive programs tend to be heavy in such personnel, often because the customer wants to retain the services they provide.

It is difficult to assess the effect of competition in the abstract. A contractor who needs business or is determined to increase market

share acts differently from one who does not.[1] A company such as Raytheon that produced both Sparrow and Sidewinder missiles may be more likely to compete hard on one missile when the volume of production on the other is low.

The volume of production to be shared in a new program may be surprisingly small. The Standard missile built at General Dynamics' Pomona Division, for example, had only 26 percent of the contract's cost. The remainder was subcontracted out to vendors chosen on a competitive basis. The warhead, rocket motor, fuze, and other equipment were Government Furnished Equipment (GFE), as is common in guided missile programs.[2] In the early competitive years of the Tomahawk program, GFE accounted for almost half of the hardware cost. In such cases the government may find it advantageous to function as a single buyer for subsystems rather than have each of two contractors purchase a smaller number.

Second-sourcing sometimes has unexpected results, as when Pratt & Whitney was brought in as a second-source to General Electric on the F404 engine. Each contractor had its own quality control system and specifications for parts finish. The differences were so great that vendors providing identically shaped pieces to both companies priced those for Pratt & Whitney as new rather than well down the learning curve.[3] More commonly, contractors find that government specifications are responsible for higher than necessary costs. Rigorous testing may be required even after the reliability of components has been demonstrated. Some vendors are specified by the customer, thus eliminating competition. The customer may resist design changes, preferring to stick with a known design that works rather than modify the design in the interests of economy.

The main deterrent to second-sourcing, however, is the cost to bring a second contractor into full production. The incremental nonrecurring costs for a complete data package for the follower for additional tooling and test equipment and for qualification testing can run into the tens or hundreds of millions of dollars. There is also the incremental cost of one or more educational buys in which items are procured from the follower who is just beginning production rather than from the leader who may be well down the learning curve.[4]

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[1]Willis R. Greer, Jr., and Shu S. Liao discuss the "hungriness" factor in *Cost Analysis for Dual Source Weapon Procurement,* Naval Postgraduate School, NDS54-83-011, October 1983. Their capacity-utilization model uses industry-wide capacity as an input, however, rather than the capacity of an individual firm.

[2]John T. Hayward, "Competition and Weapons," *Government Executive,* March 1986.

[3]*Aviation Week & Space Technology,* June 9, 1989.

[4]An educational or directed buy is a contract to provide the second source an opportunity to learn how to manufacture the product in accordance with a technical data package provided by the designer. Such buys take place before the competitive buys.

Such startup costs may be estimated with reasonable accuracy, but there are also potential increases in recurring cost from loss of learning-curve benefits and lower production rates. The problem becomes acute when a company, anticipating a high volume of production, invests in additional facilities only to learn that procurement quantities are being reduced. In all cases fixed costs must be spread over a smaller number of units when production is split between two firms. Without offsetting measures by management, product cost could increase by as much as 25 percent rather than decrease as a result of second-sourcing.

Given the Congressional requirement for two or more production sources whenever the production quantity justifies more than one source, it is essential to have a method for determining when second-sourcing will be advantageous. The problem facing the military services is not academic. Decisions involving billions of dollars in future procurement will be based to some extent on estimates of single-source vs. dual-source cost, but in view of the considerations above it is not self-evident that second-sourcing will produce savings for the government in every major procurement.

The concept of second-sourcing is not new, and numerous studies have attempted to analyze its effect on program cost.[5] Attempts to infer savings achieved in past programs have not been conclusive because the methods used for measuring savings are judgmental. The basic problem is that one cannot know the costs that would have been incurred in a single-source program had that path been taken compared with the costs that were actually incurred in the dual-source program.

Early studies concentrated on what percentage of single-source cost to the government would be saved by second-sourcing. A 1981 study based on four small missiles—Sparrow, TOW, Bullpup, and Sidewinder—illustrates this approach.[6] Savings from competition were found to amount to 4 percent from profit reduction and 8 percent from cost reduction. Based on that kind of information, the Imaging Infrared (IIR) Maverick program office chose a 10 percent overall savings factor as the most likely outcome of second-sourcing IIR Maverick production.

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[5]For an excellent summary of studies published from 1972 to 1981 see Richard J. Hampton, Price Competition in Weapons Production: A Framework to Analyze its Cost-Effectiveness, AU-ARI-84-86, Air University Press, June 1984.

[6]*An Analysis of the Impact of Dual Sourcing on Defense Procurements*, The Analytic Science Corp., August 7, 1981.

The answers obtained in competition studies have always depended heavily on the analytical methods used. A 1981 RAND study[7] showed how an analysis of prices paid for the Shillelagh missile could produce estimates ranging from a savings of 79 percent to a loss of 14 percent depending on the measured slope of the cost-quantity curve (76 to 85 percent), the procurement quantity used as a basis for calculation, and the type of cost-quantity curve (unit or cumulative average). Section IV describes five possible methods for estimating single-source costs.

[7]K. A. Archibald et al., *Factors Affecting the Use of Competition in Weapon System Acquisition*, R-2706-DR&E, February 1981.

IV. ESTIMATING SINGLE-SOURCE COSTS

Measuring the savings that accrue from dual-sourcing requires an act of faith. On one hand it is impossible to know what the costs to the government would have been in a single-source program. On the other hand unless those costs are known one has no baseline against which to compare the costs incurred in a dual-source program. Typically, the escape from this dilemma has been to estimate the costs that would be incurred with single-source procurement by projecting a hypothetical cost-quantity curve from lot costs incurred by the government before the first competitive lot. Differences between costs inferred from the hypothetical curve and costs actually incurred are attributed directly to the influence of competition. Variations on this procedure account for most of differences in results obtained in studies of second-sourcing.

A second reason for the differences in estimate of the single-source costs is that every analyst seems to be working with a slightly different set of costs. Some of the differences are due to different methods of normalizing the data; some appear to be inexplicable. For example, we found unit costs by lot for the Sparrow-7F air-to-air missile guidance and control system in five sources, and no two sets were identical. In the examples cited below, therefore, the differences in results are due to discrepancies in data as well as choice of analytical method.

INSTITUTE FOR DEFENSE ANALYSIS METHOD

The most common method for estimating single-source costs is based on the assumption that the single-source cost-quantity curve can be extrapolated from the midpoints of the two production lots immediately preceding the first competitive lot. Figure 1 illustrates this method as used in a study to estimate savings from leader-follower competition on the Sparrow-7F guidance and control section.[1] Raytheon, the leader, produced four lots—1805 units—before the start of competition with General Dynamics in FY77. A unit cost curve for the last two precompetition segments (the FY75 and FY76 lots) had a slope of 90 percent, and all subsequent single-source production was assumed to fall on that curve.

[1]George C. Daly et al., "The Effect of Price Competition on Weapon System Acquisition Cost," Institute for Defense Analysis (IDA) P-1435, 1979.

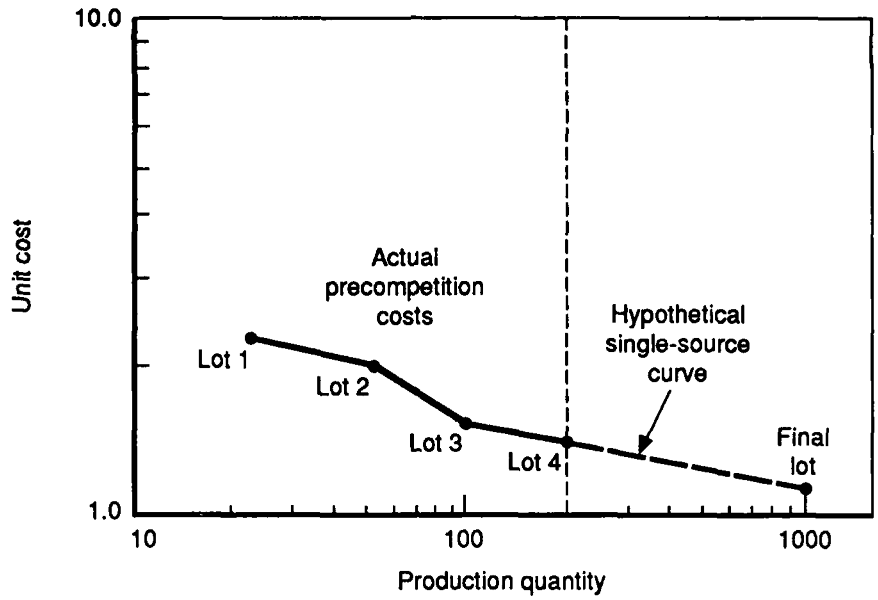


Fig. 1—IDA procedure for projecting single-source costs

A learning curve based on a sample of two lots is unlikely to give dependable estimates of the cost of subsequent lots.[2] Small distortions introduced by the need to convert then-year dollars to constant dollars, by normalizing costs to a common production rate (which was not done in the IDA study), by adjusting costs for changes in the ratio of government furnished equipment (GFE) to contractor furnished equipment (CFE), etc. can have a profound effect on slope. As an experiment, we calculated precompetition slopes for AIM-7F based on unit costs found in five sources and obtained results ranging from 85 percent to 91 percent. Extrapolated out to 10,000 units, a 91 percent curve would give an estimated cumulative cost almost 2.5 times as

[2]James S. Cullen states in an unpublished paper prepared in 1976 for the OSD Cost Analysis Improvement Group (CAIG) that approximately eight data points are required to predict eventual learning-curve slope accurately. His study was based on aircraft airframes for which early lots tend to be small—eight lots, for example, could amount to less than 100 airframes. The much larger lot sizes characteristic of tactical missile production should reduce the number of lots required to determine a cost trend. It is still true, however, as Cullen says, that "particular care must be taken in estimating from the first three actuals or in selecting a probable program learning curve from early data."

much as an 85 percent curve. We would argue, then, that in general predicted single-source learning-curve slopes cannot be accepted uncritically, but in particular those derived from the two final precompetition lots only should be regarded with care.

NAVAL CENTER FOR COST ANALYSIS METHOD

The Naval Center for Cost Analysis (NCA) prepared a report in 1988 showing the results of competition in eight selected Navy systems. The method of estimating single-source costs was similar to that described above, but the single-source curve was based on all precompetition lots except those judged to be atypical. In the case of the Standard Missile-2 (SM-2) guidance and control system, for example, the final precompetition lot was excluded because NCA believed that the price had been affected by competition. The FY85 and FY86 lots were excluded from the Phoenix 54C missile analysis because NCA believed the prices to be "artificially low." And in the case of the AEGIS Cruiser (CG-47), a single-source learning curve of 96 percent was assumed because the shipbuilder (Ingalls) had a history of no slope at all—a 100 percent curve—on single-source contracts.

This procedure resulted in curve slopes ranging from 83 percent to 96 percent. In five of the eight examples the curves are steeper than they would have been had the IDA method been used.

NONLINEAR ESTIMATION

An unpublished OSD/PA&E study by Gary Bliss estimates single-source costs in three ways—nonlinear, linear, and worst-case—for the same missile programs.[3] Nonlinear estimating is similar to the NCA procedure in that single-source projections are based on all precompetition lots except those considered atypical. Lot 1 of Sparrow-7F, for example, was excluded because it was said to have had unusual production problems. Nonlinear estimation differs from the NCA method in that unit prices of all lots are adjusted to a common production rate.

This study derived values for production-rate elasticities from "step-ladder" quotes in which the competing firms submitted bids for different quantities of missiles based on possible share ratios—30/70, 40/60, 50/50, etc. For example, if a total buy is 400 units, both firms may quote on quantities of 120, 160, 200, 240, and 280. Such bid data, available for three of the four missile programs examined (AIM-7F,

[3]Gary Bliss, *Dual Sourcing in Defense Missile Procurement*, 1987, unpublished.

AIM-7M, AIM-9L, and AIM-9M), permitted the derivation of rate elasticities for both prime and second sources. The rate elasticities used to adjust single-source prices, the normalization quantities, and estimated single-source learning curve slopes are shown in Table 3. The AIM-9L rate elasticity is a weighted average of all prime and second-source values.[4]

LINEAR ESTIMATING

"Linear" estimating builds on the widely held opinion that the effect of competition on product cost can be represented by the simple model shown in Fig. 2. The underlying assumption is that before competition the cost-quantity curve will be fairly flat. When competition begins, cost drops sharply (shifts) and the cost-quantity curve becomes steeper (rotates). The usual method for measuring shift and rotation is as follows: A cost-quantity curve is calculated based on the unit costs of the two lots immediately preceding the first competitive lot. That curve is extended to the midpoint of the first competitive lot to obtain a hypothetical unit cost with single-source procurement. The difference between that hypothetical cost and the unit cost of the first competitive-buy lot is the shift. Rotation is the difference in slope between the precompetition curve and the curve established by the unit costs of the first and second competitive lots. In programs with only one precompetition lot, such as Ford Aerospace's AIM-9L and AIM-9M, no shift or rotation can be calculated.

Table 3

VALUES USED TO ADJUST SINGLE-SOURCE PRICES

Missile	Rate Elasticity	Normalization Quantity	Estimated Learning Curve Slope (%)
AIM-7F	−0.2310	1000	93.1
AIM-7M	−0.2321	2000	93.0
AIM-9L	−0.3134	1500	93.7
AIM-9M	−0.2076	2000	94.4

[4]Actual unit costs of each lot are normalized to a common quantity in the following manner:

$$\text{Normalized cost} = (\text{Actual cost})(\text{Common rate}/\text{Actual rate})^a$$

where a = Rate elasticity.

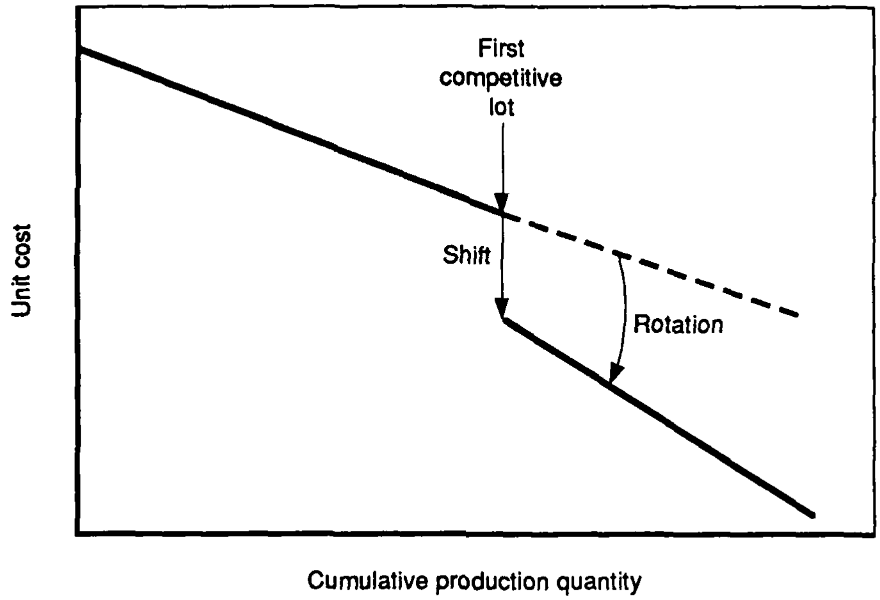


Fig. 2—Shift and rotation

Bliss used data from the same four air-to-air missile programs mentioned above to examine the hypothesis that competition has a systematic effect and that a model can be derived that includes shift and rotation as separate independent variables. That hypothesis makes it possible to use unit costs from all production lots instead of only precompetition lots if one believes that shift and rotation factors derived from other programs are relevant to the present programs. In the case of the AIM-7F, for example, the single-source cost-quantity curve would be based on seven lots rather than two as in the IDA method or four as in nonlinear estimation. The functional form of this model is:

$$C_R = KQ^{R(DR)-b}e^{s(DS)}$$

Where: C_R = rate-adjusted unit cost
Q = quantity
R = rotation factor
DR = rotation dummy variable (0 or 1)
e = error term
S = shift factor
DS = shift dummy variable (0 or 1)
b = learning curve slope

In the absence of competition the dummy variables are set equal to zero, and single-source learning curve slopes may be obtained as shown in Table 4. The slopes are essentially the same as those obtained by the nonlinear method. In the two cases with the smallest number of lots, AIM-7M and AIM-9L, the shift and rotation dummy variables proved not to be statistically significant, and the difference in magnitude among the variables indicates little consistency in shift and rotation effects from program to program.

WORST-CASE ESTIMATING

Worst-case estimating is based on the premise that unit cost is free from competitive pressure only in the first production lot. Thereafter, if second-sourcing is being considered, the contractor will price his product lower than would be the case in a pure sole-source environment. Consequently, the single-source cost-quantity curve must be extrapolated from the Lot 1 unit cost. The slope of that curve is established by the fact that this is "worst-case" estimation; that is, the analyst chooses the flattest curve slope consistent with the type of equipment being produced. Bliss used a 90 percent slope to obtain the results shown in Table 5. (In the case of the AIM-7F Lot 1 data could not be used because of extreme technical problems with the missile. The second lot also had problems, so Bliss used the Lot 3 unit cost.)

Table 4

VALUES DERIVED FROM LINEAR HYPOTHESIS

Missile	Rotation Factor	Shift Factor	Estimated Learning Curve Slope (%)
AIM-7F	−0.285	2.145	93.1
AIM-7M	−0.040	0.252	93.0
AIM-9L	−0.227	1.686	93.7
AIM-9M	−0.305	2.550	94.4

Table 5

ESTIMATED SAVINGS OR LOSS FROM DUAL PROCUREMENT
(Percent)

Method	AIM-7F	AIM-7M	AIM-9L	AIM-9M
IDA	+5.0	−16.8	+24.0	+12.2
NCA	−10.3	−28.6	+18.9	+12.7
Nonlinear	+1.5	−20.6	+13.0	−35.4
Linear	−1.5	−21.0	−2.5	−15.1
Worst Case	+9.0	+5.3	−3.8	−5.7

DIFFERENCE IN RESULTS

Using the five methods above, we estimated the hypothetical single-source cost for the AIM-7F, 7M, 9L, and 9M programs and compared those with actual dual-source program costs. Table 5 summarizes the results. The IDA method makes the best case for second-sourcing with savings in three of the four cases. Linear estimation does not show savings in any of the four programs. NCA, *worst-case*, and nonlinear estimation show savings in two and losses in two. There is no consensus on any of the four programs, but three of the five methods show savings for the AIM-7F and AIM-9L. It must be noted that these are undiscounted savings. If costs were discounted at an annual rate of 10 percent as specified by DoD practice, estimated savings would look slightly better.

These results neither confirm nor refute the argument that second-sourcing has been a useful procurement technique for reducing military system costs. They do point out that estimating single-source costs is as problematic today as it was in the 1970s. Predictions of future events are inherently uncertain, and small differences in estimated single-source slope can have a major effect on estimated savings. Based on worst-case assumptions, actual costs in the AIM-7F program were 9 percent lower than estimated single-source costs. Based on NCA assumptions, they were 10 percent higher.

Future Programs

The methods described above were developed for the purpose of estimating costs of single-source procurement in past programs, but estimators use comparable techniques to project single-source costs in programs for which second-sourcing is being considered as a

procurement strategy. The Tomahawk cruise missile program, discussed in more detail in Sec. VII, provides a good example of how three organizations arrived at substantially different estimates of single-source cost. All made straight-line projections based on precompetition lots, but the organizations differed in their decisions about which of the four precompetition lots to use. More important, they adjusted the basic cost data differently in attempting to achieve year-to-year comparability.

It may seem academic to prefer any one method of projecting single-source costs when the results may depend primarily on the way in which lot costs are normalized, but of the five methods described here we believe the NCA approach is the most reasonable. It is also the most subjective. An analyst has to decide which lot costs are atypical and which may have been influenced by the prospect of competition. It recognizes that single-source costs are not obtained by mechanically fitting a curve to two or more points; they must be based on representative costs to date, company history, and company capabilities.

V. THE EFFECT OF COMPETITION

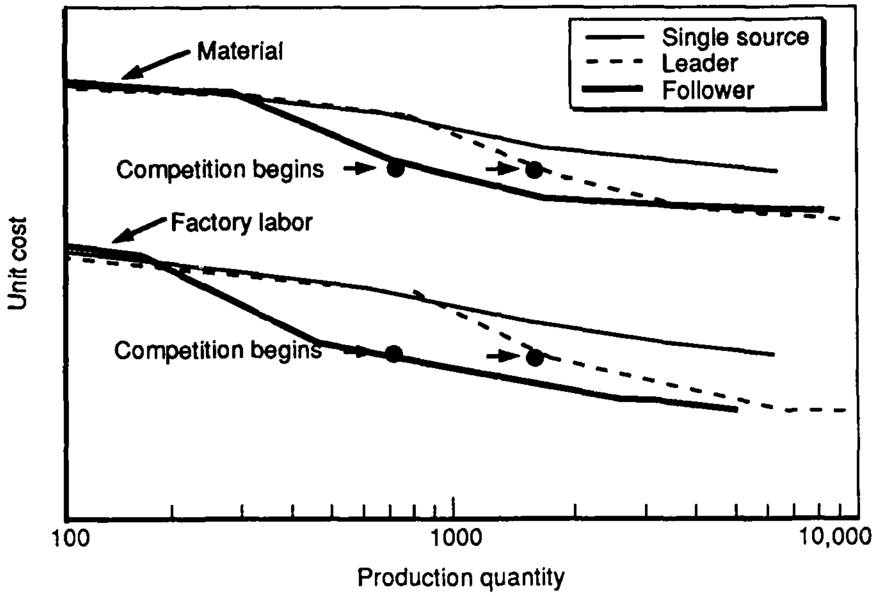
One can argue that the disadvantages of second-sourcing—the cost of entry for a second producer, the lower production rates, and the lower production quantities—are likely to offset any advantages of competition. The evidence indicates, however, that in many cases contractors respond more strongly to competitive pressure than one would expect. Consequently, when unit cost in the early lots seems too high and predictions of future lot costs do not show appreciable cost reductions, second-sourcing may be a reasonable alternative. There is, however, no reliable method for predicting the effect of second-sourcing. Both the timing and the magnitude of cost reductions are uncertain.

The shift-and-rotation hypothesis described in Sec. IV is often relied on for predictive purposes, usually at the unit-cost level but sometimes at the producer's functional-cost-element level (engineering support labor, manufacturing labor, factory support labor, and materials). The Advanced Medium Range Air-to-Air Missile (AMRAAM) program provides an interesting example of this second approach. The Armament Division developed an estimating model based on AIM-7F and AIM-9L data that treated material, factory labor, and System Engineering/Program Management separately. Figure 3 shows the sharp decrease in unit cost predicted by the model at the point where competition begins.

Raytheon, primary contractor on the AIM-7F, AIM-7M, AIM-9L, and AIM-9M and the secondary contractors on the AIM-7F and AIM-9L (General Dynamics/Pomona and Ford Aerospace), supplied data to allow us to investigate the AMRAAM approach independently.[1] We wish to ascertain, first, do shift and/or rotation occur in every instance? Second, if they do, is there any consistency or regularity to such effects? A third question is more speculative; given evidence of shift and/or rotation, what actions by the contractors are responsible for such cost reductions?

As described in Sec. IV, calculations of shift and rotation are usually based on the two precompetition and two postcompetition lots; but the precompetition curve could be calculated by any of the methods described in the previous section, and the postcompetition curve could be based on all competitive lots. The "usual" method was followed in obtaining the results below, because that method is common to most

[1]No precompetition curve could be constructed for the Ford Aerospace AIM-9L because there was only one precompetition lot.



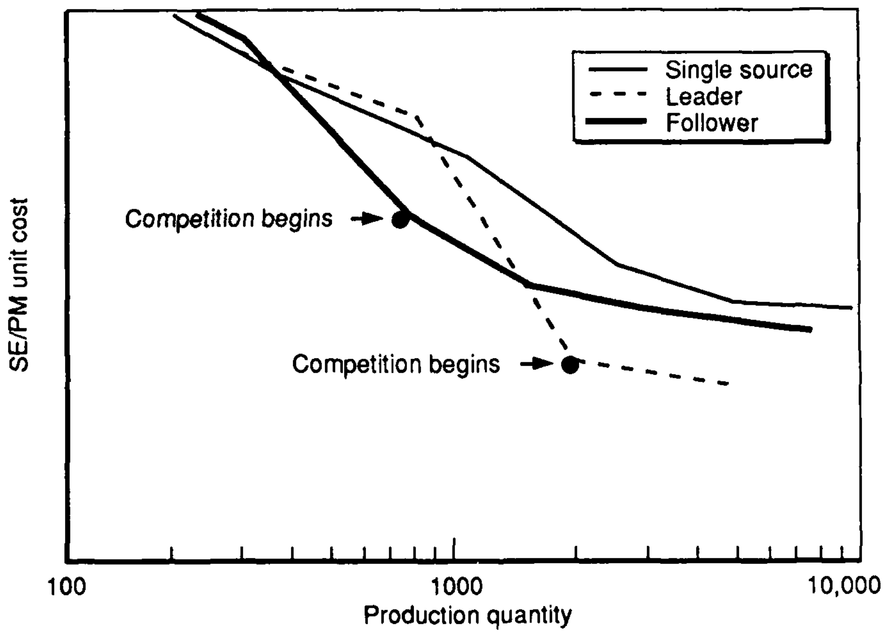


Fig. 3—The effect of competition according to the AMRAAM model

studies supporting the shift-and-rotation hypothesis. Different methods would produce different results, however, and the results shown here are exemplary rather than definitive.

FUNCTIONAL-LEVEL ANALYSIS

Materials generally account for the largest percentage of the producer's cost. As the term is used here, "materials" include raw and semifabricated materials, purchased parts (standard items such as electrical fittings, valves, and hydraulic fixtures), and purchased equipment (actuators, motors, generators, etc.). Such items are purchased from vendors; thus cost reductions by a prime contractor have to be achieved by squeezing the vendors a little harder, changing the make/buy mix (i.e., the mix of items manufactured in-house and those procured from vendors), or changing the equipment design to save on material cost. Given sufficient motivation, contractors can reduce the cost of materials even though smaller quantities may mean a loss of quantity discounts.

The problem for one who is trying to predict what will happen in a new program is that, as shown in Table 6, the initial effect of competition is not consistent. Shift and rotation generally occur, but not always. The magnitude of both varies considerably. Rotation is shown in percentage points—the difference between the slope of the pre- and postcompetition curves. In the case of the greatest shift, the AIM-9M, material cost increased sharply in the second competitive lot and produced a strong upward rotation of the curve.

Factory labor is all the direct labor necessary to fabricate, assemble and install purchased parts and equipment, and to inspect and test to ensure prescribed standards are met. The labor learning curve for

Table 6

CHANGE IN MATERIAL COST

Item	Shift (%)	Rotation (% pts)
Leader		
AIM-7F	−15	−7
AIM-7M	−6	0
AIM-9L	+3	−2
AIM-9M	−18	+54
Follower		
AIM-7F	−4	−1

manufacturing companies is generally fairly steep, and one would not expect it to be influenced much by competition. It is surprising, however, to see that in our small sample of missiles (see Table 7) an upward shift was the rule and the learning curve was more likely to flatten than to steepen.

Engineering support labor covers engineering labor used to address problems and effect changes as well as preparation and maintenance of drawings, process and material specifications, configuration management, process control at the vendors, etc. Engineering and factory support labor are primarily level-of-effort activities. The sharp decline in hours per unit in successive lots occurs because roughly the same number of hours is being allocated across a larger quantity of missiles. Moreover, the number of workers assigned to each of those activities is to some extent discretionary. For example, one missile production facility we visited in 1986 had 30 support engineers assigned to a single-source program compared with three in a comparable dual-source program. The difference was attributed to the fact that in the single-source program the contractor could include in the hardware price a number of services wanted by the customer. In a dual-source program those services are more likely to be separate contract items or to be eliminated.

The shift-and-rotation hypothesis cannot be applied directly to engineering and factory support, because labor hours per unit are influenced more strongly by lot size than by cumulative production quantity. As shown in Fig. 4, unit hours tend to drop sharply in the second or third production lot as quantity increases. Unit hours increase in the first AIM-9L(R) competition lot because quantity decreases. To examine for shift and rotation it is necessary to normalize unit hours to a constant lot size (or production rate). For AIM-7F, for example, the two pre- and two postcompetition lot sizes were 600, 880, 1100, and

Table 7

CHANGE IN FACTORY LABOR HOURS

Item	Shift (%)	Rotation (% pts)
Leader		
AIM-7F	+4	+3
AIM-7M	+3	+1
AIM-9L	+18	−7
AIM-9M	+6	−9
Follower		
AIM-7F	0	+2

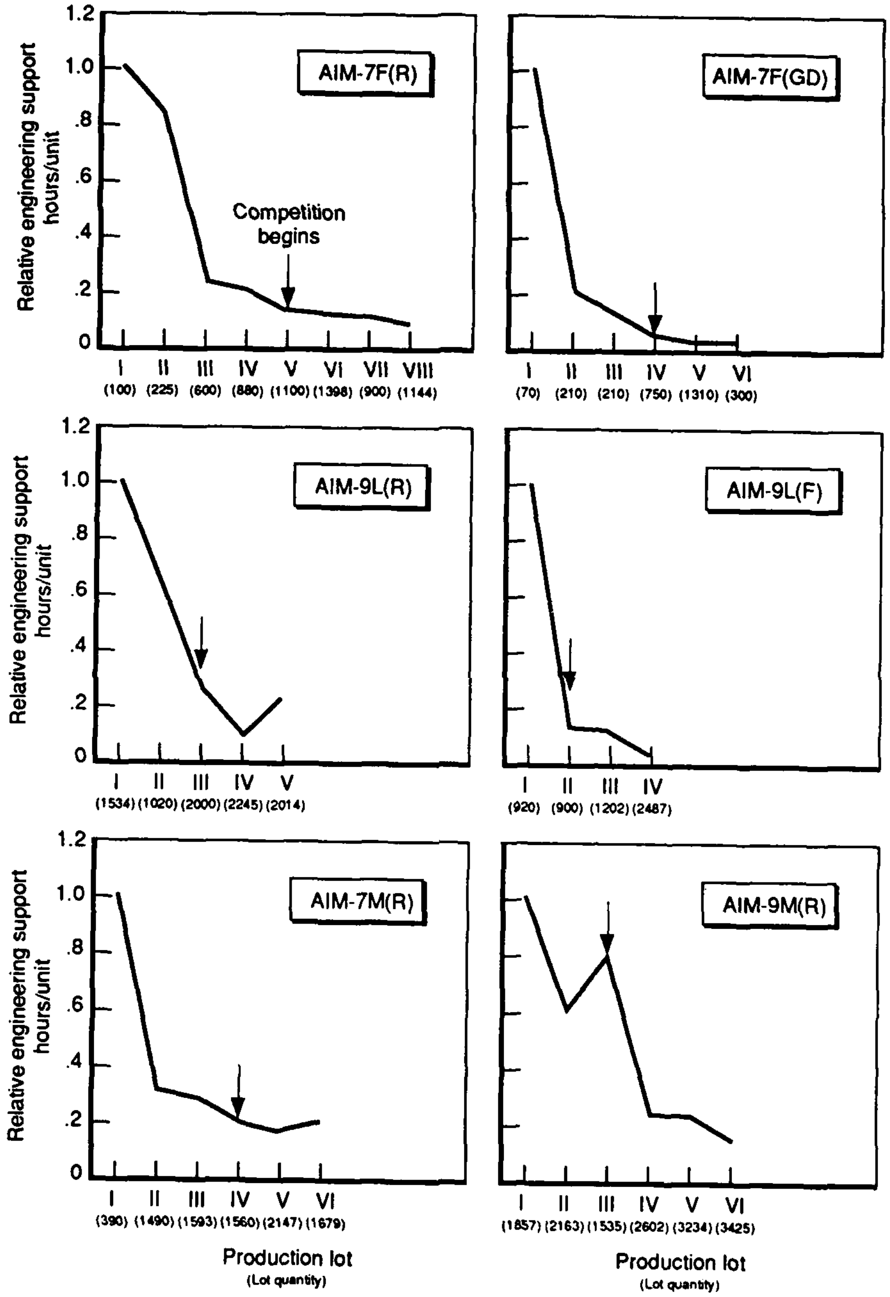


Fig. 4—Engineering support hours

1398. We normalized them all to 1000 units using the procedure described in Sec. IV for nonlinear estimating. The rate elasticity for engineering hours typically has a value of 0.737 to 0.621, which makes it comparable to a 60–65 percent learning curve. We assumed a conservative value of 0.621, which has the effect of changing the basic engineering hours by the factors shown in Table 8.

Admittedly, this procedure can only approximate the actual unit hours, because the rate elasticity will be different for every firm and for every program. Consequently, Table 9 does not present percentage values for shift and rotation but only whether competition produced the predicted effect (a negative change) or a positive change in the first competitive lot. Results for both unadjusted and rate-adjusted values are shown.

The rate-adjusted results differ from those of the unadjusted in only two instances. The AIM-7M shift changes from upward to downward, and the AIM-7F (Follower) shift changes in the opposite direction. In most of the cases engineering support labor hours did decline as expected, but the premise that there will be both shift and rotation is not completely dependable.

Table 8

RATE ADJUSTMENT

Lot Size	Factor
600	.728
880	.924
1100	1.061
1398	1.231

Table 9

CHANGE IN ENGINEERING SUPPORT LABOR HOURS

	Unadjusted		Rate-adjusted	
Missile	Shift	Rotation	Shift	Rotation
Leader				
Sparrow-7F	–	+	–	+
Sparrow-7M	+	–	–	–
Sidewinder-9L	–	–	–	–
Sidewinder-9M	+	–	+	–
Follower				
Sparrow-7F	–	–	+	–

Manufacturing support labor includes incoming inspection, material qualification, various screening and acceptance tests, production planning, and rework. Figure 5 shows relative unit hours by lot for four missile programs; in most cases the plots show the same patterns observed for engineering support hours. To examine shift and rotation, therefore, it is again necessary to adjust for rate, and we used the same rate elasticity, 0.621, that was used for engineering support. As shown in Table 10, the rate adjustment produced more changes in the results for this cost element. Without adjusting the data, downward shift and rotation were observed in four of the five cases. After adjustment it appears that upward movement of the curves is as likely as downward.

Overall, the cost-element data display no consistent characteristics or patterns that would enable one to identify when competition began or which lots were procured in a competitive environment. Where the cost-quantity curve steepens, many different factors are influencing cost, such as increased production rate, engineering design stabilization, workforce stabilization, etc. For material there appears to be some evidence of a downward shift but little to support the concept of a downward rotation of the curve. For factory labor a downward shift did not occur when competition began, and the curve rotated downward in only two of the four missile programs. Engineering and manufacturing support labor showed the largest percentage cost reductions, and these are the areas in which a contractor has the greatest opportunity for reductions in labor. However, they account for less than 20 percent of unit cost in the cases considered.

UNIT-COST-LEVEL ANALYSIS

Estimating the effects of competition at the unit-price level appears reasonable to us because (1) there is interplay among the functional cost elements and (2) changes in labor and overhead rates, general and administrative (G&A) expenses, and profit are included. A contractor decides on a price when making a bid, not on the hours or dollars associated with each cost element, and the constituents of that bid need not be consistent from lot to lot. A reduction in engineering hours, for example, may be translated into an increase in profit rather than a reduction in price. Consequently, if the shift-and-rotation hypothesis is to be used for estimating savings to the government, it would be preferable to estimate at the total-recurring-cost level where one has some assurance of capturing all costs. And if the shift-and-rotation pattern exists, one should be able to perceive it at the unit-cost level.

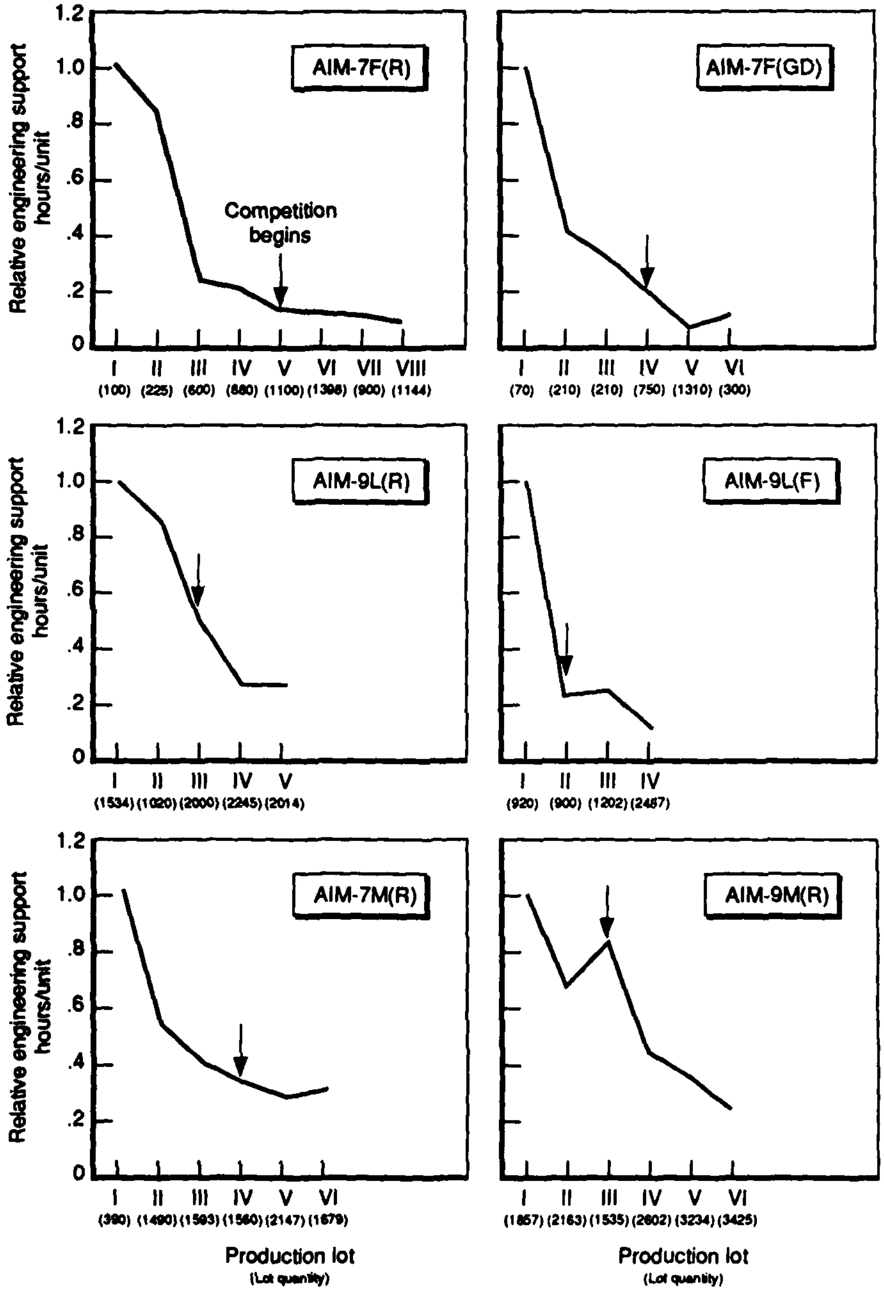


Fig. 5—Factory support hours

Table 10

CHANGE IN MANUFACTURING SUPPORT LABOR HOURS

	Unadjusted		Adjusted	
	Shift	Rotation	Shift	Rotation
Leader				
AIM-7F	−	+	−	+
AIM-7M	−	−	−	+
AIM-9L	−	−	+	−
AIM-9M	+	−	+	−
Follower				
AIM-7F	−	−	+	−

Using the IDA procedure described earlier, we calculated unadjusted and rate-adjusted shift and rotation values at the unit-cost level for the same five cases using the rate elasticities derived by Bliss. For comparative purposes we also calculated values using the linear method described in Sec. IV. The results tend to support the concept of shift and rotation. Using the IDA method with no rate adjustment a downward shift occurs in three instances and a downward rotation in all five. When costs are adjusted to a common production rate, a downward shift occurs in four cases and downward rotation in three. The linear method produces shift and rotation in all cases. Thus, it is reasonable to believe that shift and rotation can be assumed for the purpose of comparing estimated single-source costs with estimated second-source costs, but Table 11 offers little guidance in choosing shift and rotation values.

Figure 6 illustrates the difficulty of generalizing about leader-follower programs. Leader and follower unit costs, shown in relative terms, make it clear that no single rule regarding the effect of competition prevails. In three of the four programs most of the cost reduction occurred during the directed-buy phase—before formal competition began. One could argue that the threat of competition motivates the leader firm to offer its product at a reduced price, and that apparently happened in some programs. It cannot be a common practice, however, because the leader is guaranteed the larger share of a directed buy. Also, reducing price before competition reduces the potential for later price cuts.

Figure 6 also illustrates how the relationship between leader and follower costs varies from program to program. An important aspect of competition is the dynamic interaction over time between leader and

Table 11

UNIT COST SHIFT AND ROTATION

Missile	IDA-unadjusted		IDA-rate adjustment		Linear	
	Shift (%)	Rotation (% pts)	Shift (%)	Rotation (% pts)	Shift (%)	Rotation (% pts)
Leader						
AIM-7F	−10	−7	−11	−7	−6	−16
AIM-7M	−3	−4	−4	+16	−8	−3
AIM-9L	−36	−27	−22	−18	−15	−14
AIM-9M	+6	−42	−6	−16	−2	−18
Follower						
AIM-7F	+11	−4	0	+9	—	—

follower. Sidewinder-9L exemplifies the expected response pattern. Both contractors reduced their bids in the first year of competition, the leader by 37 percent. The leader won the larger share again the following year with a 16 percent price reduction. Then in the final year the follower won 55 percent of the production quantity by making a 35 percent cut in price. Sidewinder-9M shows the same interaction with each contractor being low bidder for two of the four competition lots.

Sparrow-7F is distinctly different. The leader had no real competition until FY79 and had little incentive to make substantial price reductions. Between FY75 and FY79 (two directed buys and three competitive buys) the leader's unit cost decreased only 46 percent while the follower was able to reduce his by 76 percent. Leader and follower unit costs tend to converge in all programs, but that did not happen until near the end of the production run.

The main point made by Fig. 6 is that the facts do not lend themselves to a simple model. In these four programs major price reductions occurred before the start of formal competition or in the first, second, or third competitive lot. The largest cost reduction did not necessarily occur at the time competition began, but these programs may not be typical. The eight Navy systems examined by NCA show a somewhat different pattern of behavior between leader and follower.

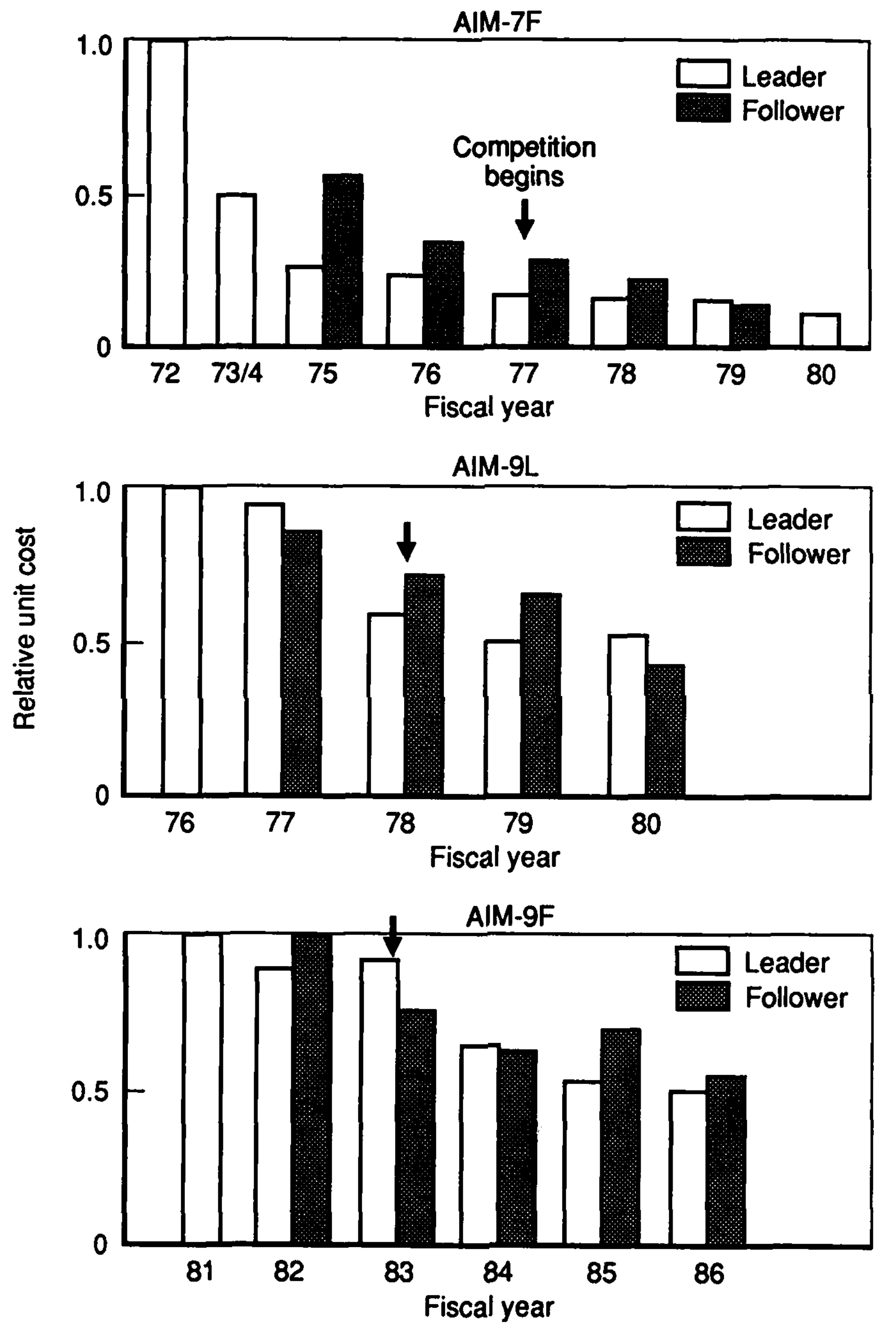


Fig. 6—Relative cost by fiscal year

NCA COMPETITION STUDY

The 1989 NCA study does not discuss theories or concepts of competition; it is merely a presentation of the results of eight case studies as they appeared at that time. (Where final price was still in doubt, as in the case of ship construction, estimates at completion were used.) We cite the study here, because it implicitly makes a strong case for the shift hypothesis. A downward shift in price occurred in all eight cases, the smallest, 6 percent, being on the Tomahawk AUR, and the others ranging from 17 to 36 percent. We examine seven of these cases briefly to determine whether program characteristics can be observed that would suggest when second-sourcing would be appropriate. The Tomahawk AUR is treated separately at some length in Sec. VII. Table 12 shows the NCA estimates of costs and savings.

Table 12

NCA ESTIMATES OF COSTS AND SAVINGS
(Millions of FY89 $)

	Estimated Savings (%)		2d-Source Startup Cost as percent of Sole-Source Cost
	Undiscounted	Discounted	
SM-2 GC&A through FY94	19	15	5.0
SM-2 motor through FY94	24	23	0.4
Phoenix GC&A through FY92	1	-3	10.0
CG-47 through FY88	18	16	1.2
LSD-41 Five ships	28	26	0.4
TAO-187 through FY88	8	5	3.0
VLS Launcher through FY94	16	15	0.5

STANDARD MISSILE-2 BLOCK 2 GUIDANCE, CONTROL, AND AUTOPILOT/BATTERY SETS (SM-2 GC&A)

General Dynamics/Pomona was the single-source producer of Standard Missile GC&A sets for a number of years as technology evolved from SM-1 to SM-2 Block 2. From FY82 to FY86 price followed a 93 percent slope; then in FY87 after Raytheon had been brought in as a competitor and awarded a directed buy of 200 units the GD/Pomona curve shifted downward by 10 percent. By FY88, the first year of head-to-head competition, GD/Pomona had built almost 4000 Block 2 GC&A sets but was able to reduce price by another 30 percent. Raytheon's FY88 bid also showed a substantial downward shift.

STANDARD MISSILE-2 ROCKET MOTOR

Morton Thiokol Inc. (MTI) was the only producer of Mark-104 dual-thrust rocket motors for SM-2 from program inception in FY83 to FY87 when Atlantic Research Corp. (ARC) won a qualification and limited production contract. MTI prices were following a 96 percent learning curve before the first competitive buy in FY88. Although MTI had produced approximately 2500 SM-2 rocket motors before competition began, the firm found it possible to reduce price by 32 percent in FY88. Future reductions were expected to be small.

PHOENIX-54C GUIDANCE, CONTROL, AND AIRFRAME SETS

Hughes Aircraft Company developed the Phoenix-54C GC&A and was the only producer from FY79 to FY85. The program experienced considerable cost growth on the early contracts, and production was stopped in the mid-1980s because of hardware problems. The Navy chose Raytheon as second source and awarded that company learning, qualification, and directed-buy contracts in FY86, 87, and 88, respectively. Competition began in FY89. Until that time Hughes had produced about 1500 units, and price was following an 88 percent learning curve. Price shifted downward by 17 percent in FY89 and was projected to continue down an 88 percent curve. Raytheon, however, underbid Hughes in FY89 by about 2 percent. Savings are negligible because of above average second-source startup costs and because half of the total missile quantity was procured before competition.

CG-47 (AEGIS CRUISER) CLASS SHIPS

Ingalls Shipyard and Drydock (ISD) won a contract to build the lead ship, the CG-47, for the AEGIS cruiser program in FY78 and won contracts for an additional eight ships in FY80–83. Ship price declined very little between FY78 and FY82; but when Bath Iron Works (BIW) won a second-source contract in FY82, ISD responded with an 18 percent price reduction in FY83. Head-to-head competition in FY84 produced another downward shift of 15 percent. The ISD cost-quantity curve slope for FY84–88 was a surprising 75 percent.

LSD-41 (LANDING SHIP DOCK) CLASS SHIPS

The original LSD-41 and -42 contracts were Cost Plus Award Fee (CPAF), but the LSD-41 contract was converted to Cost Plus Fixed Fee (CPFF) in November 1984 based on forecasts that Lockheed would overrun target cost. The LSD-42 contract was converted to Fixed Price Incentive (FPI) because of "poor contractor cost performance." Excluding the lead ship, LSD-41, the single-source learning curve would have been 88 percent; but Navy procurement officials believed that the level of cost was too high. With five more ships to be built the Navy decided on winner-take-all competition instead of second-sourcing. After Avondale Industries won that competition with a bid that was 36 percent below the level of the single-source curve, two of the six competing shipyards, Lockheed and General Dynamics/Quincy, went out of business.

TAO-187 CLASS SHIPS

This class of ships has been competed since program inception in a series of three blocks. In Block I Avondale Industries won a winner-take-all competition to build four ships and achieved a 90 percent learning curve. When second-sourcing was introduced for Block II procurement, Avondale reduced ship prices by about 18 percent but was underbid by Pennsylvania Shipbuilding Company. Penn Ship was awarded four ships, Avondale, three. Unfortunately, Penn Ship's target prices were too low. Because of financial problems the third and fourth ships were transferred to Avondale for completion. Avondale won the Block IIIA competition and it was assumed would win Block IIIB as well. Both are single-source, and prices are on about a 90 percent curve.

MARK-41 VERTICAL LAUNCH SYSTEM (VLS) LAUNCHERS

Martin Marietta Aerospace and Naval Systems designed and developed the VLS and was the only producer in FY82, 83, and 84. The Navy decided that the Northern Ordnance Division of Ford Manufacturing Corporation should become a second producer "in the interest of national defense." NCA gives the Martin Marietta sole-source learning curve as 80 percent on the FY82–84 lots. However, if the slope is based on the two precompetition lots only, the curve is actually positive. With head-to-head competition price was immediately reduced by 28 percent, and the curve rotated to 83 percent. In four years of competition, each contractor has won the larger share of production twice.

OBSERVATIONS

Second-sourcing has produced a shift, a rotation, or both in every case examined here, thus demonstrating that competition has had a perceptible effect in these cases. One cannot infer, however, that second-sourcing will produce savings in all cases; because we do not have a random sample. Procurement agencies decide on second-sourcing when that approach appears to offer a financial advantage. Admittedly, there are other important reasons for bringing in a second producer as in the case of the VLS where the national interest was invoked, but some savings are still expected. Single-source procurement is preferred when it appears more efficient, and there are examples of single-source programs in which steep cost-quantity curves were achieved. For example, in a sample of seven single-source missile programs for which published data were available, we found only one, Harpoon, that started with a 90 percent curve, and the curve on that program rotated to 70 percent after 1250 units had been produced. In all others, as shown below, slopes of 85 percent or better were maintained out through at least 1400 units. At that quantity unit cost has declined to 18 percent of Unit 1 cost (assuming an 84 percent curve), so further savings would be slight in any event.

Basic Hawk: 76% cumulative average curve to unit 12,323
HARM: 82% to unit 1441; 90% from 1442 to 2841
Harpoon: 90% to unit 1250; 70% from 1251 to 1950
Maverick A: 85% to unit 17,000
Phoenix A: 71% to unit 1223; 85% from 1224 to 2385
Redeye: 82% to unit 2033; 72% from 2034 to 25,020
Stinger: 84% to unit 5229; 82% from 5230 to 7283

The examples discussed in this section (other than the seven single-source cases above) consist of selected cases in which *a priori* judgments were made that two producers would be preferable to one. After the fact, those judgments appear sound. The results, however, do not lend themselves to generalizations about shift and rotation that would be useful in estimating savings from second-sourcing. Estimating at the functional-cost-element level does not appear promising, nor does stipulating percentage values for shift and rotation. As we have seen, both the timing of such changes and their magnitude can vary greatly from program to program. Rather than estimate savings, a program manager may approach the second-sourcing issue by asking what production quantity would be required for the estimated cost to the government of dual-source procurement to equal that of single-source procurement. That "breakeven" approach is discussed in the next section.

VI. BREAKEVEN ANALYSIS

Although there is no reliable method for predicting the dollar value of savings from second-sourcing, the basic question is not how much money will be saved, it is whether the introduction of a second source will generate financial benefits or penalties. One way to make that determination is on the basis of a breakeven analysis.[1] The breakeven approach does not require an explicit estimate of the second source's production costs but rather deduces the magnitude of savings needed to justify a second source. This deduced value can then be normalized and compared with historical values that have actually been achieved to assess its reasonableness.

In general terms "breakeven" refers to the point at which the expected cost to the government of the dual-source alternative equals the cost of the sole-source alternative. This can be expressed by the following relationship:

$$TC_{ss} + \text{Investments}_{ss} = TC_{c1} + TC_{c2} + \text{Investment}_{c}$$

Where:	TC_{ss}	= Total recurring cost of the single-source contractor after competition begins
	Investment_{ss}	= Additional investment required to bring the single-source contractor to full production rate capability
	TC_{c1}	= Total recurring cost for first contractor
	TC_{c2}	= Total recurring cost for second contractor
	Investment_{c}	= Investment required to bring both contractors to dual-source production rate capability

Proponents of this method assume that the investment required (both Investment_{ss} and Investment_{c}) can be estimated accurately based on investment costs already incurred by the initial contractor. Total recurring cost of the single-source contractor (TC_{ss}) is estimated

[1]Milton A. Margolis, Raymond G. Bonesteele, and James L. Wilson, *A Method for Analyzing Competitive, Dual Source Production Programs*, presented at the 19th Annual DoD Cost Analysis Symposium, September 1985. Richard J. Hampton, *A Price Competition in Weapons Production: A Framework to Analyze Its Cost-Effectiveness*, AU-ARI-84-6, Air University Press, June 1984.

based on an extrapolation of the existing cost-quantity curve. Estimates of TC_{c1} are based on the shift-and-rotation hypothesis with recommended shift values ranging from a few percent to 15 percent and rotation values from 1–5 percent. The analyst is expected to choose appropriate values based on "contractor experience, competition results on comparable programs, contractor eagerness, viability of potential competitors, etc."

The equation is solved for the least understood term, TC_{c2}, total recurring cost for the second contractor.

$$TC_{c2} = TC_{ss} + \text{Investment}_{ss} - (TC_{c1} + \text{Investment}_{c})$$

TC_{c2} is not an estimate; it represents the cost the second source would have to charge for second-sourcing to break even. To place the required savings in perspective, TC_{c2} is compared with the sole source's estimated cost over the same quantity interval on the cost-quantity curve. The specific parameter that is calculated is termed the "undercut percentage":

$$\text{Undercut percentage} = 1 - \frac{TC_{c2}}{\text{Base}_{ss}} \tag{100}$$

Where: Base_{ss} = estimated cost to the government when competitive buy quantity is procured from the initial sole source

The final requirement after computing the undercut percentage is to decide whether second-sourcing is a reasonable course of action. Based on the results of half a dozen second-source programs, the proponents of this method relate undercut percentages to savings in a "stoplight" chart:

Undercut Percentage	Stoplight Color	Likelihood of Savings
0–10	Green	Reasonable expectation
11–20	Yellow	Difficult but achievable
21–30	Orange	Very difficult
30+	Red	No verified achievement

The breakeven method is not as simple as this summary description implies. An analyst is expected to examine the sensitivity of the results to variations in production rate and quantity, the percentage of procurement costs affected by competition (some portion of unit cost may be associated with common vendors), the single-source learning

curve, and the shift and rotation percentages. Also, the analysis is conducted in discounted present-value dollars—a DoD requirement when trading off current investment against future savings.

The OSD/CAIG has used this method on a number of programs, and the results have been considered useful. It seems to us that its greatest utility would be in programs for which the undercut percentage is very low or very high, say under 10 percent or over 40 percent. The message in such cases would be clear: dual-source for the former, single-source for the latter. Intermediate undercut values are more ambiguous because of the problems enumerated in previous sections. First, it is necessary to extrapolate a single-source cost-quantity curve from early lot data, and the slope of that curve depends on the extrapolation procedure—IDA, nonlinear, worst-case, etc. Second, shift and rotation values must be assumed based on "known" values for comparable programs, but we have found little agreement on such values. Also, the NCA study suggests that shift is more likely than rotation. Third, the criterion for judging potential second-source programs—the undercut value—is based on the assumption that one can distinguish between past programs that have shown savings and those that have had losses. As we have seen, these results are often equivocal.

Table 13 shows achieved undercut percentages calculated at PA&E for four dual-source programs and compares them with the estimated savings shown in Table 10. An undercut value of 5 percent for the AIM-9L is consistent with the fact that three of the extrapolation procedures indicate savings of 13 to 24 percent, and the mean of all five is a savings of 10 percent. An undercut of 10 for the AIM-7M, however,

Table 13

COMPARISON OF DISCOUNTED ESTIMATED RESULTS
AND UNDERCUT VALUES
(Percent)

	AIM-9L		AIM-7M		AIM-7F		AIM-9M	
	Savings	Loss	Savings	Loss	Savings	Loss	Savings	Loss
Method								
IDA	23			15	7		12	
NCA	19			23		9	12	
Nonlinear	13			18	4			36
Linear		2		18		1		15
Worst case		4	4		11			6
Undercut	5		10		25		25	

should indicate a reasonable expectation of savings, yet four of the five analyses point strongly toward a substantial loss. Also, it seems to us that an undercut of 25 percent for both the AIM-7F and AIM-9M would be misleading.

Part of the problem of interpreting achieved undercut percentages is that they are derived from programs with different production quantities. The savings or the potential to achieve savings increases as production quantity increases. Everything else being equal, achieved undercut percentages would be higher for high-volume programs. Hence, an undercut of 25 for about 9000 AIM-7F missiles does not have the same meaning as an undercut of 25 for over 25,000 AIM-9M missiles. Perhaps when the data are normalized for both production rate and quantity the undercut values would be easier to interpret.

A more straightforward use of the breakeven method is to calculate the production quantity required for the cost of second-source procurement to equal that of single-source procurement. Figures from the AMRAAM program illustrate this method. The Air Force estimate of July 1985 showed a savings of $685 million (FY84 $) for 24,375 missiles, broken down as shown in Table 14:

The increase in nonrecurring and other program costs (allowing for engineering change orders, data, training, etc.) was more than offset by an assumed 18 percent reduction in recurring costs. All told, however, a 9 percent savings based on a production quantity of over 24,000 missiles is not itself reassuring, because production quantities frequently change. Funding may not be available, the threat may change, or new technology may dictate a major model improvement. If the decision to bring a second producer into a program hinges on cost considerations, it is essential to know the breakeven quantity. For AMRAAM the projection based on 1985 program office estimates would have been 11,000 units without discounting or 17,000 units using a 10 percent per year discount rate (see Fig. 7).

Table 14

JULY 1985 AIR FORCE ESTIMATE
OF COMPETITION SAVINGS
IN AMRAAM PROGRAM

	Millions of $	%
Nonrecurring	−120	−63
Recurring	+917	+18
Other program	−112	−5
Total	+685	+9

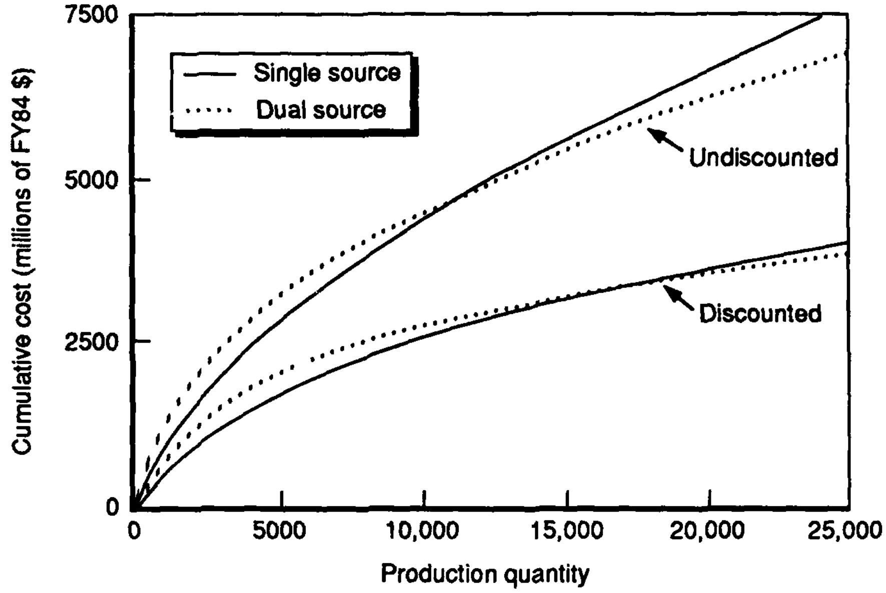


Fig. 7—AMRAAM breakeven curves, 1985 estimate

At the time the 1985 estimate was made, second-sourcing had been decided upon, and estimates were firm enough to be certified to Congress by Secretary of Defense Weinberger. When estimates are less certain, curves can be drawn to determine breakeven quantities under whatever range of assumptions appears reasonable for a particular situation.

What assumptions do appear reasonable? The critical assumption concerns the slope of the single-source learning curve, and that assumption may have to be made after only one or two lots are under contract. Even with additional lot prices, however, one has no assurance that the cost trend can be predicted accurately. Presumably, a program manager considering second-sourcing has some indication that unit price is not going to decline rapidly. More specifically, his information should indicate that the slope would be no steeper than 85 percent.

There is a rough correlation between single-source slope and the rotation of a dual-source curve: The flatter the slope, the greater the rotation. Based on our data, with a 90 percent single-source curve it

would be conservative to expect a 5 percent rotation; 10 percent would not be unreasonable. Figure 8 illustrates how breakeven quantity could be plotted as a function of those variables, the incremental investment cost of second-sourcing, and the precompetition quantity. As an example, with a precompetition quantity of 100 units and an incremental investment cost of $25 million the breakeven point would be between 330 and 525 units (the example assumes rotation but no shift).

This method does not eliminate any of the uncertainties inherent in predicting the effect of competition, but it does show how the assumptions affect the results. We believe this kind of information would be more helpful to a decisionmaker than a range of undercut percentages.

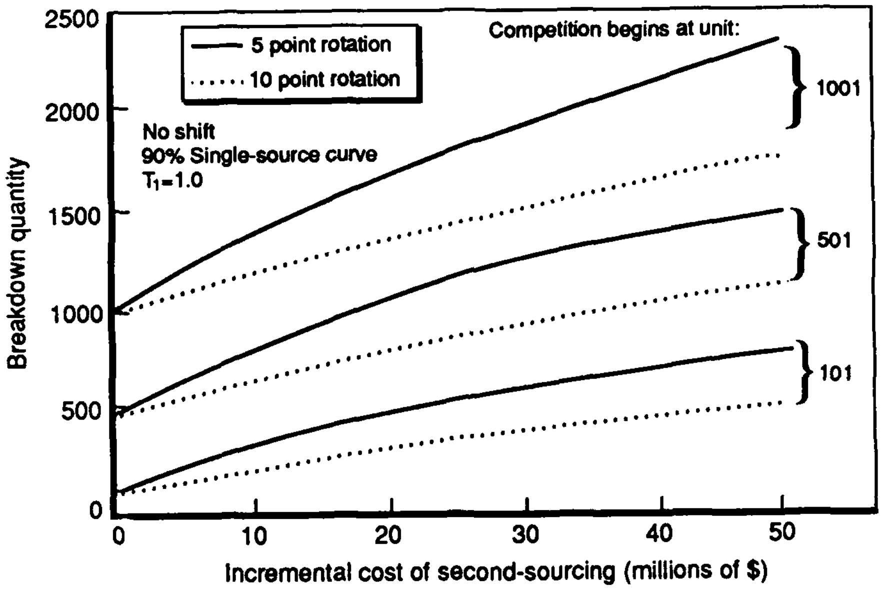


Fig. 8—Breakeven quantity vs. incremental cost

VII. THE TOMAHAWK EXPERIENCE

The Tomahawk project provides an interesting example of the use of second-sourcing to achieve several goals: to reduce the risk of interrupted or unsatisfactory production, to reduce program cost, and to improve missile reliability. Almost from program inception in 1977 the Joint Cruise Missile Project Office directed extensive use of dual competitive sources for all major elements of the missiles. The largest dual-source arrangement involves the Tomahawk AUR, of which there are two major types, the Navy's Sea-Launched Cruise Missile (SLCM) and the Air Force's Ground-Launched Cruise Missile (GLCM). Within those types there are land-attack (TLAM) and antiship (TASM) missiles that are distinguished by different guidance systems.

During development, General Dynamics' Convair Division had the responsibility for the airframe and flight vehicle integration of both missiles, and McDonnell-Douglas had responsibility for the guidance systems. The JCMPO considered second-sourcing both airframe and guidance as early as 1978, but total planned production of SLCM and GLCM amounted to only about 1100 units. When that quantity was increased to 4554 in late 1980, the JCMPO began negotiating with the two contractors to get them to exchange technology so that each could produce AURs, a flightworthy missile contained in a launch-compatible canister or capsule.

At that time JCMPO believed that GD/C costs were too high and that quality assurance problems were not receiving sufficient attention. Second-sourcing appeared to be a way to deal with both issues. When contracts with GD/C and MDAC were signed in 1982, it was believed that competition could produce savings in excess of $500 million excluding investment associated with capitalization of tooling and test equipment. The dual-source estimate was based on a reduction of 7.9 percent in average unit flyaway cost achieved in the GD/C contract after negotiation of the agreement between GD/C and MDAC. The single-source estimate was based on a detailed "will cost" analysis by the Navy, executive service for the program.

GD/C began building Tomahawk missile airframes and MDAC guidance sets, in 1981. Each contractor provided kits to the other in FY82 and FY83 to transfer the required technology in preparation for competition to begin in FY84. MDAC was not fully ready for head-to-head competition at that time, however, so both contractors were awarded directed buys of 36 AURs; competition began in FY85.

An immediate effect of the second-sourcing agreement was that both GD/C and MDAC made strenuous efforts to reduce operating costs. GD/C established a nonunion, modern, low-cost facility in Abilene, Texas, to manufacture air vehicle components. MDAC built a modern, low-cost production facility in Titusville, Florida; but lack of missile airframe production volume kept them from being competitive until FY87. The JCMPO assumes that MDAC made a corporate decision to win in that year, and they did win a 60 percent share by substantially underbidding GD/C.

GD/C responded by instituting several cost-reduction measures, including moving more machining work to the Abilene facility. That firm won a 70 percent share in FY88, then MDAC came back to win the FY89 competition with an average unit price 50 percent lower than its FY88 price. Thus, after a slow start, competition had a visible effect in FY87, 88, and 89. The interplay between the two contractors demonstrates the dynamics of competition at work, but those dynamics have never been in question. The question is whether second-sourcing in the Tomahawk has produced savings. To answer that question we must return to the issue of single-source costs.

SINGLE-SOURCE ESTIMATES

As described in Sec. IV, there are many ways to estimate single-source costs. CMP, GD/C and NCA each looked at the costs and production quantities of the first four lots (FY81–84), and each arrived at a different set of numbers to use as a basis for projecting a single-source cost-quantity curve. Table 15 shows the AUR recurring costs

Table 15

TOMAHAWK LOT COSTS AND QUANTITIES, FY81–84
(Millions of $)

	FY81		FY82		FY83		FY84	
	Cost	Qty	Cost	Qty	Cost	Qty	Cost	Qty
CMP	117.5	57	221.6	142	152.7	108	324.0	244
GD/C	a	57	a	142	a	108	a	244
NCA	75.5	57	155.9	132	75.6	64	181.0	172

[a]The GD/C costs lie between CMP's and NCA's. GD/C considers the actual figures to be proprietary.

and quantities each organization used for those years. The NCA quantities are different in FY82–84 because technology-transfer and directed-buy AURs are excluded. The costs differ because each organization adjusted actual contract costs to achieve year-to-year comparability, but each followed a different procedure. First, AUR prices had to be constructed for the years before FY85 because airframes were bought from GD/C and guidance sets from MDAC, except for the directed-buy AURs in FY84. In relying on contract costs where the AUR is not a line item, it is possible that non-AUR items (booster, Ground Support Equipment (GSE), trainers, etc.) could be included with the airframe. Second, Tomahawk is a family of missiles with different launch modes and different missions. Year-to-year price comparisons can be misleading unless adjustments are made to compensate for changes in the mix of variants.

CMP METHOD

The CMP estimated single-source costs, first, by calculating theoretical unit prices for Lots 1 through 4 (FY81–84). GD/C airframe and integration prices and MDAC guidance set prices were combined to obtain a weighted average for each year. Normally, the estimate of single-source costs would have been obtained by extending a cost-quantity curve through the last two precompetition lots, but the CMP believed that the technology transfer program in progress in FY83 and FY84 could have introduced a competitive element into the contract prices for those years. Consequently, the single-source learning curve was based on Lots 1 and 2 only. That curve had a slope of 87.1 percent and a theoretical first unit cost of $4.628 million. Based on that curve, the recurring cost of 4591 AURs would have been $5.42 billion (TY $) or $5.65 billion (FY89 $).

GENERAL DYNAMICS/CONVAIR METHOD

GD/C had some reservations about the CMP study, saying that some non-AUR costs were included in the FY81–82 CMP numbers. CMP disagrees, but whatever the reason GD/C's theoretical T_1 is below CMP's, and the GD/C single-source learning curve has a slightly flatter slope. When that curve is projected out to 4591 units and converted to FY89 dollars, we obtain an estimate of $5.13 billion, about $500 million less than the CMP estimate.

NAVAL CENTER FOR COST ANALYSIS METHOD

NCA data provide a third estimate of single-source cost. As noted previously, NCA included only joint production AURs in FY81–84—those procured under the original arrangement with MDAC furnishing the guidance sets and GD/C furnishing airframes and performing the integration task. Normalized prices for FY81–84 were derived by summing airframe and guidance unit costs for each variant, then computing the mean values of the sums. The curve fitted to the resulting four points had a 90 percent slope and a T_1 of $2.89 million (FY89 $). When that curve is projected out to 4591 units, the recurring single-source cost estimate is $4.17 billion, $1 billion less than the GD/C estimate. Thus, three different estimating methods give vastly different estimates of single-source cost.

DUAL-SOURCE ESTIMATES

After competition began in FY85 the CMP began a "break back" policy—items that the Navy had previously procured and provided to the contractors as GFE were converted to CFE. The reference measuring unit computer and cruise missile radar altimeter, for example, were GFE for FY81–87 missiles and CFE thereafter. Other items became CFE in FY89. In addition to normalizing the raw price data for price-level changes and variant mix, therefore, it was necessary to stipulate a constant AUR configuration to project price trends. In the Tomahawk case the normalization procedures resulted in three sets of numbers. We are not concerned here with the accuracy of any set of numbers or the advisability of the procedures. The point is to illustrate the problems inherent in estimating savings from second-sourcing.

CMP ESTIMATE

In 1987 the CMP projected a savings of $1.2 billion (then-year dollars) over the period FY81–93 for a total buy of 4591 AURs. That estimate is based on "actual" dual-source costs up through the FY88 buy and an extrapolation of those costs for FY89–93. AUR costs were reconstructed for FY81–84, and actual contract prices used for FY85–88. However, all prices were normalized to reflect the AUR configuration of FY85–87. Cumulative recurring cost to the government was estimated to be $4.16 billion.

Figure 9 compares cumulative total cost including special tooling and test equipment costs (in FY85 $). According to that view, dual-

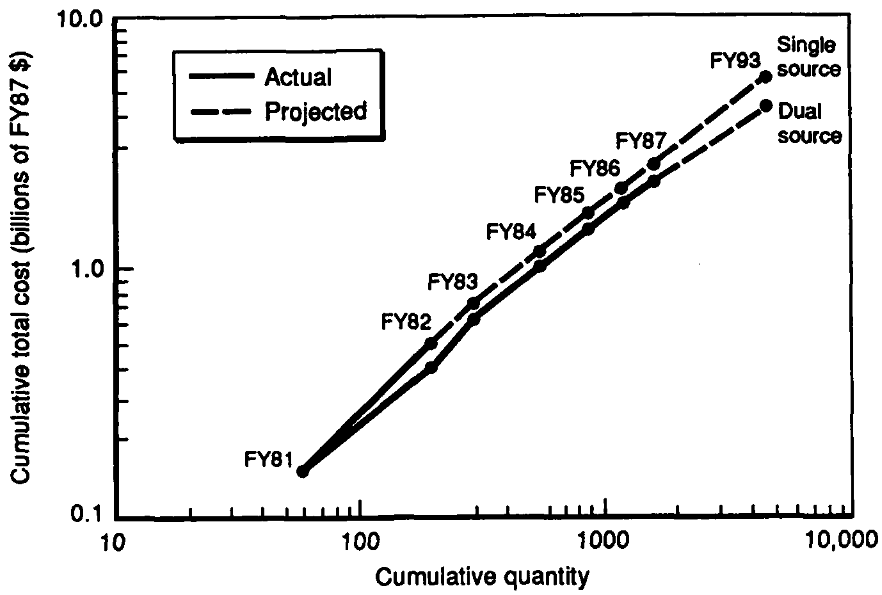


Fig. 9—1987 CMP cumulative cost comparison

source production was always the less costly alternative. A major reason is that in the single-source case CMP assumed that all nonrecurring costs would have been incurred early in the program—in FY82-84—because production could have started sooner. Dual-source nonrecurring costs began later and continued longer. Normally, the costs of tooling, test equipment, qualification, etc. needed to bring a second contractor to the point where he can compete with the original producer make dual procurement more costly initially. Because of the earlier investment in special tooling and test equipment in the single-source alternative, second-sourcing appears more attractive from the outset of production.

GD/C DATA

GD/C prepared a comparison of single- and dual-source costs in 1988 but did not project costs beyond FY88. Figure 10 shows the two unit curves. The dual-source AUR unit cost does not fall below the single-source cost until about 700 units have been produced. A

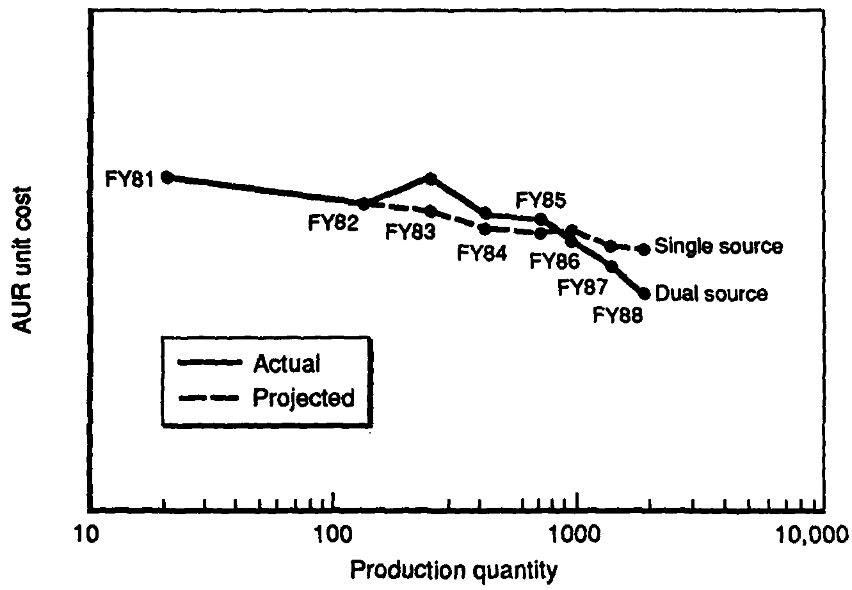


Fig. 10—1988 GD/C view of AUR unit costs

comparison of cumulative costs shows that the dual-source alternative does not break even until FY87. Even in the GD/C comparison, however, the cost risk in implementing second-sourcing was minor, because the incremental nonrecurring cost was said to be small. When both curves are projected out to 4591 units, total potential savings through FY93 are estimated to be $433 million (FY87 $).

NCA DATA

Figure 11 is based on NCA data. The single-source unit cost curve, derived from joint-production prices in FY81–84, has a 90 percent slope. The dual-source curve includes joint-production, tech transfer, and directed-buy AURs in the precompetition years. Each plot point is a composite of GD/C and MDAC prices. When the data are plotted in this way, AUR unit price did not fall below the single-source curve until FY87, the third year of competition. The breakeven point in terms of total cumulative recurring cost occurred at about 1500 units. When startup costs of $88 million are included, breakeven does not occur until FY88 after approximately 2000 units have been produced.

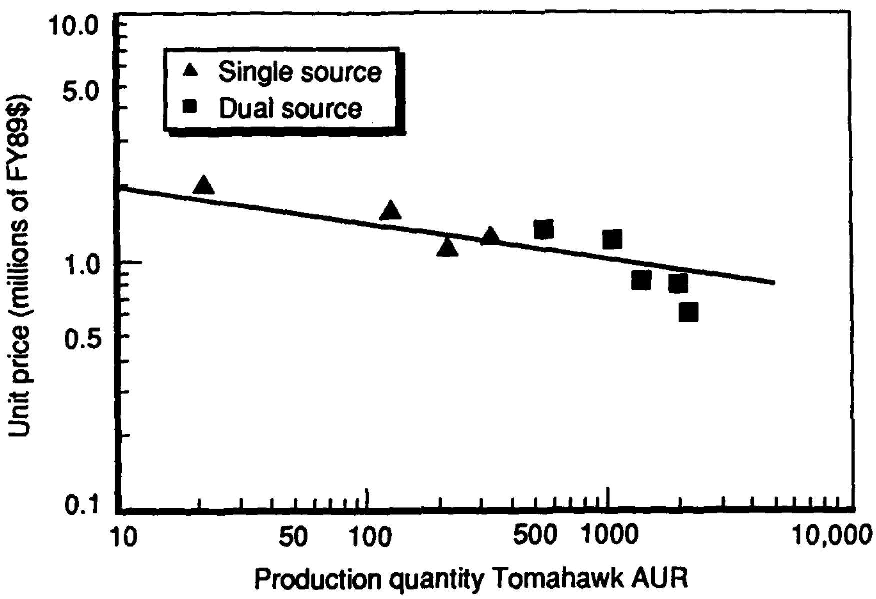


Fig. 11—Unit price comparison based on NCA data

OBSERVATIONS

Two conclusions can be drawn from the comparisons above. First, predictions about when second-sourcing will pay off and how much money will be saved are highly uncertain. From the studies above it can be inferred that the breakeven quantity was 130, 1400, or 2000 units, and that quantity was achieved before the start of competition or in the second or fourth year of competition. The differences are due to the way each organization adjusted the basic data to achieve year-to-year comparability in a very complicated program, and the differences in incremental nonrecurring costs—FY87 dollars: CMP, $35 million; GD/C, $59 million; NCS, $83 million. All the numbers are fairly small, presumably because of the CMP's policy of expecting contractors to bear a larger share of initial investment costs in return for an opportunity to amortize those costs over the production program. By comparison, incremental investment costs to establish second sources on two Air Force air-to-air missile programs, AMRAAM and IIR Maverick, were estimated by their program offices to be $135 million and

$100 million respectively. Both missiles are much smaller and cheaper than Tomahawk. Thus, while the comparison is not exact, it does illustrate how procurement policy can affect tradeoff studies of second-sourcing.

The second conclusion is that despite the differences noted above, second-sourcing has apparently produced savings for the government in the Tomahawk program. The estimated value of those savings in FY89 dollars ranges from $400 million to $1.25 billion (FY89 $) for a buy of 4500 missiles. The NCA estimate of savings is $550 million undiscounted or $270 million discounted. All these estimates are based on the assumption that prices will continue to decrease; but even if price levels off in the remaining years of production, the program will show savings.

THE EFFECT OF COMPETITION

Figures 12 and 13 show the interaction between GD/C and MDAC in the competitive environment beginning in FY85. AUR prices are in relative terms and are normalized to reflect the FY85–87 AUR

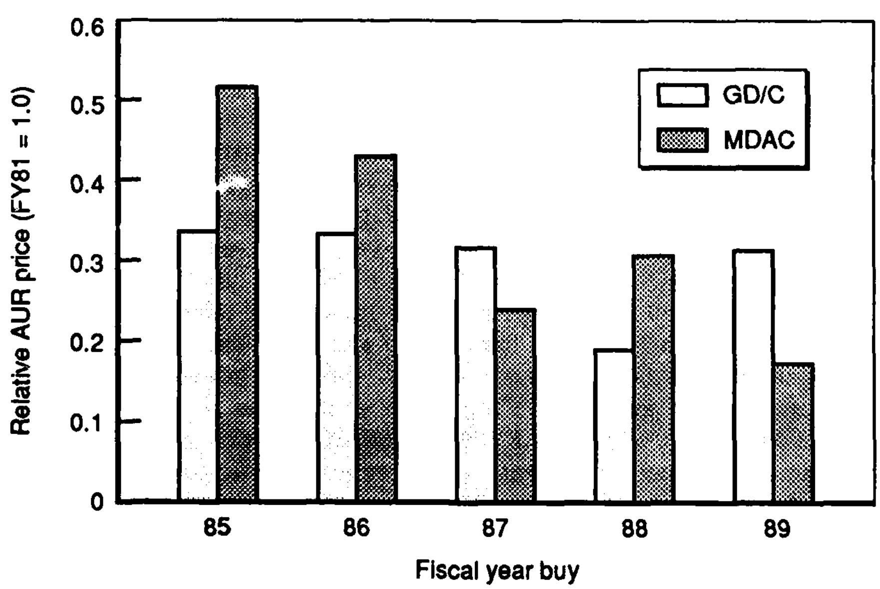


Fig. 12—Relative AUR prices

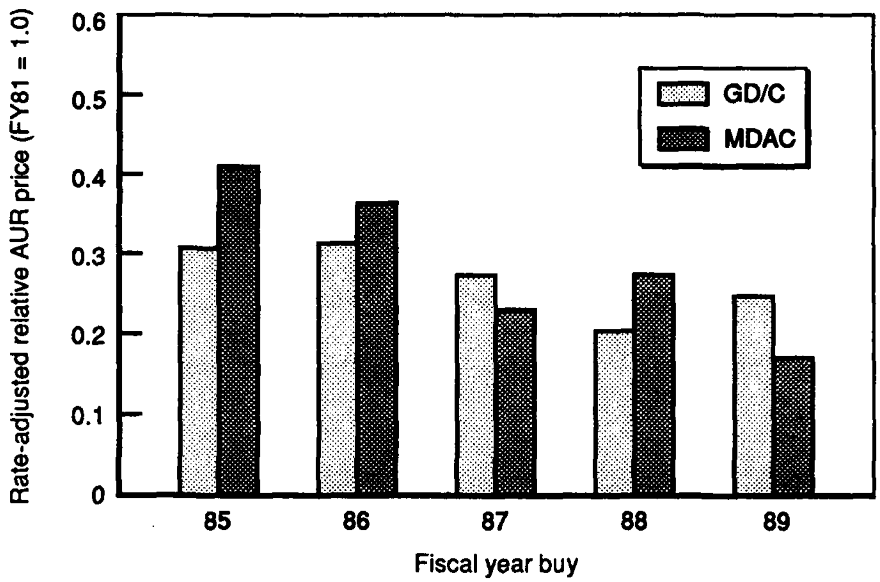


Fig. 13—Rate-adjusted relative AUR prices

configuration. The figure indicates that GD/C was not strongly influenced by the shift and rotation hypothesis in setting prices. Price differences between the two contractors are accentuated by the differences in the number of AURs awarded to each contractor, but even allowing for that, some of the year-to-year changes are remarkable. GD/C reduced AUR price very little in FY85, and unit price actually increased in FY86 for a slightly larger number of missiles. A small price reduction in FY87 was followed by a major reduction in FY88 in response to MDAC's previous year bid. MDAC, however, raised its unit price by 40 percent in FY88 (with a reduction in quantity from 240 to 143 units). Then in FY89, as the GD/C price went up again, this time by almost 20 percent, MDAC reduced AUR price by over 50 percent.

None of the competition theories we have looked at would produce this kind of a pattern. The GD/C shift and rotation as measured by the two precompetition and two postcompetition lots were both upward. Price then moved unpredictably up and down. The combined

GD/C and MDAC price, however, can be represented fairly accurately by an 87.6 percent cumulative average curve, which represents a rotation of 3.3 percentage points from the cumulative average single-source curve. The existence and magnitude of rotation appear to depend on how rotation is measured. When rotation is based on the first two competitive lots only, it may turn out to be positive as we saw in Sec. V. When all competitive lots are used as a base for measurement, a positive rotation is never seen. Tomahawk data indicate a rotation but no shift; other cases support the notion of a shift but no rotation.

Contractors clearly do respond to competition, but the timing and nature of those responses vary. The success of second-sourcing in the Tomahawk program was due to specific factors that will not be found in every major system acquisition program. First, the cost of entry for a second producer was low—less than 2 percent of the projected production cost of over 4000 missiles. Second, the original contractor, GD/C, projected a fairly flat learning curve in its own studies. It was not hard to demonstrate savings when single-source target prices were established at the GD/C level. Third, annual award quantities were large enough to absorb fixed and semi-fixed production costs without distorting AUR unit costs unduly. Finally, the CMP worked hard and effectively at managing the competition aspects of AUR procurement.

COMPARISON WITH AIR-LAUNCHED CRUISE MISSILE

Dual-sourcing may have been the proper choice for Tomahawk, but it would not necessarily be the best choice for all cruise missile programs. The Joint Cruise Missile Project offers an unusual opportunity to compare single- and dual-source procurement in a framework where many of the elements are common. The Air-Launched Cruise Missile (ALCM) emerged from a formal competition between a Boeing design, the AGM-86B, and an air-launched SLCM derivative proposed by GD/C, the AGM-109. Boeing won the competition in a flyoff conducted by the JCMPO in 1980. During the ALCM flyoff plans were made for a competitive production phase, but single-source procurement was decided upon, partly because there were second sources for the engine and inertial navigation element, and redundant suppliers for large portions of the airframe had been developed.

Figure 14 compares the ALCM cost-reduction experience with that of Tomahawk. Out through the first 500 missiles Boeing achieved a 77 percent improvement curve. Cost then leveled off and increased slightly, but at 1600 units the single-source ALCM had declined to a lower fraction of its Unit 1 cost than had Tomahawk. One can only

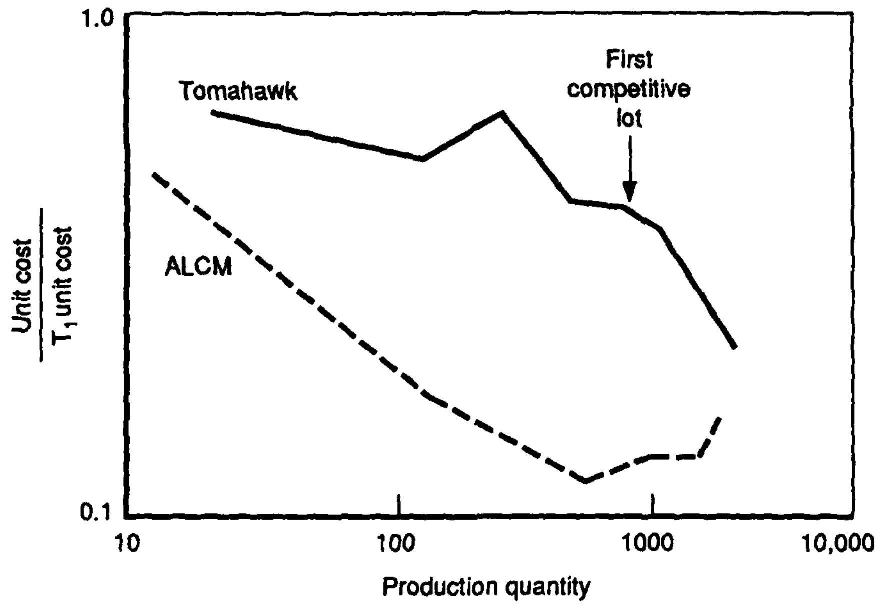


Fig. 14—Comparison of Tomahawk and ALCM programs

speculate whether GD/C's projected single-source curve was more conservative (flatter) than the curve that GD/C would have achieved if it had been selected for single-source procurement.

VIII. PRODUCT QUALITY

According to the CMP, the primary reason for second-sourcing the Tomahawk AUR was not to reduce cost but to improve quality assurance procedures. The CMP was seriously concerned with Tomahawk reliability during system development and was not satisfied with GD/C's effort to deal with the problem. Since nothing gets management's attention as effectively as the prospect of having to share production with a competitor, CMP began thinking about second-sourcing early in the program.

It is difficult, however, to establish a cause-and-effect relationship between second-sourcing and improved quality. Quality improves over time in all programs as more tests are conducted and problems isolated, and that was true in the Tomahawk program. The question is whether a link between second-sourcing and quality improvement can be shown.

We know that (1) uncorrected quality assurance problems existed on and off between 1978 and 1982, (2) dual-source procurement was authorized in 1982, (3) system reliability as measured by flight-test results improved in the period 1983–86. We also know that CMP did not rely exclusively on second-sourcing to influence GD/C to focus on the quality assurance problem. The Defense Contract Administration Services Plant Representative Office (DCASPRO) issued five Method C corrective action requests between November 1981 and May 1982 to deal with what CMP perceived as serious quality assurance problems. In June 1982 DCASPRO issued a Method D corrective action request, an action that is taken only "after sequentially exhausting every other avenue available by the Government to obtain corrective action by the manufacturer." Reliability showed a perceptible improvement by mid-1983, and overall missile reliability eventually achieved a level comparable to that of other missile programs.

Should one expect dual-procurement programs to have a better reliability record than single-source programs? Unlike studies of the cost issue, studies that explicitly examine the effects of second-sourcing on product quality are hard to find. One might reasonably expect some such effect, but the extent, even the direction, of the effect is problematic. On one hand it can be argued that:

- The second source would be starting the production learning process all over again and would suffer from quality problems that the original source had already solved.

- The increased emphasis on low production cost might create new quality problems in both suppliers.

On the other hand:

- The second source could benefit from most of the first source's experience and thus start out producing items of superior quality.
- Enhanced competitive pressure would lead both suppliers to improve quality.

Measuring product quality can be contentious, because no single quantitative index of product quality is widely accepted, nor are there generally accepted procedures for evaluating the marginal worth of some incremental improvement in quality. It would be desirable to examine several measures of quality for a variety of past programs to see if any of them could be correlated with the introduction of a second manufacturing source. In the time available for this study, however, we were able to collect consistent and reliable data across several weapon systems for only one index: flight test results. That limitation is not as restrictive as it might seem. Flight test reliability information may be the best single parameter that can be used, because it provides a good indication of whether a missile will hit a target.

Flight test data were collected on two single-source programs, TV Maverick (Hughes) and ALCM (Boeing), and two dual-source programs, Imaging Infrared Maverick (Hughes and Raytheon) and Tomahawk (GD/C and MDAC). By comparing the flight test reliability histories of those programs we believed it would be possible to discern differences between single-source and dual-source programs. We considered several reliability models for the estimation and forecasting of reliability and chose the Lloyd-Lipow model because (1) it is specifically designed to deal with attribute data as an input (test results measured only in terms of a success or a failure), and (2) the appropriateness of this model for use in estimating system reliability from and for development data is generally accepted.

In brief, the Lloyd-Lipow model calculates overall system reliability as a function of the number of failures and the number of tests. Failures are weighted to accommodate small sample sizes and the capability to improve the design in the remainder of the development phase. We examined reliability in both the short term (the first 15 flights) and the long term. The TV Maverick is compared with the IIR Maverick and the ALCM with Tomahawk.

Figure 15 shows the smoothed data for the first 15 test flights of the Maverick missiles. The TV Maverick, a sole-source program, had only

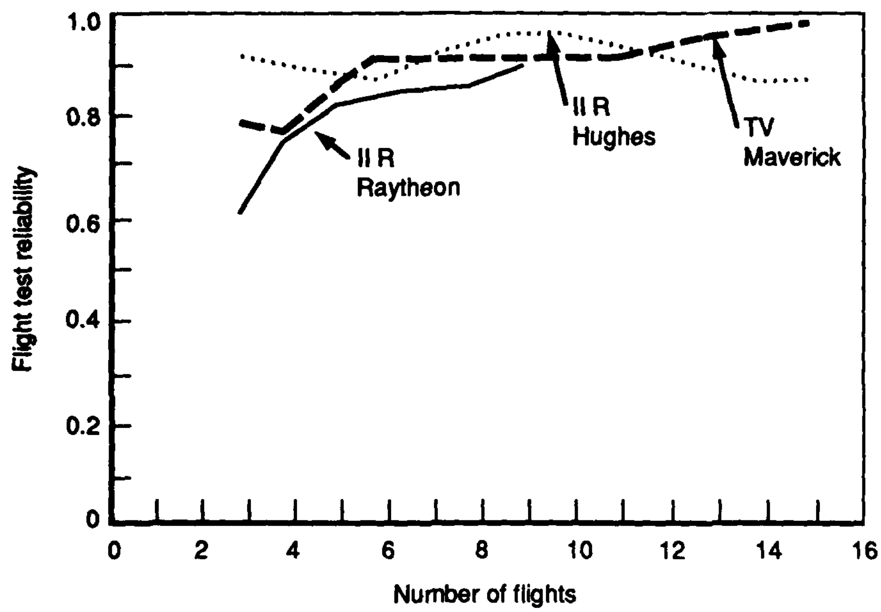


Fig. 15—Composite of short-term Maverick test results

two failures in its early flight phase. Consequently, the smoothed curve shows an end point reliability of 96 percent, the highest of all the reliabilities at that point in the test program. The Hughes IIR Maverick also had a very successful early flight test program with only four failures and an end-point reliability of 86 percent. Raytheon, the second source for IIR Maverick, was required to have a flight test program to qualify as a producer. Our data include data on only the first 11 missiles flight tested, but up to that point the program was quite successful with only two failures. The end-point reliability is 89 percent, slightly below the Hughes reliability at the ninth flight but not statistically different.

Figure 16 shows the smoothed data for long-term test results for TV Maverick and IIR Maverick (Hughes). There is no perceptible difference in reliability between the missiles. The reliability curve for the first hundred or so flights shows that reliability has become asymptotic at 98–99 percent. For the IIR Maverick the curve is asymptotic to a reliability value of about 98 percent. Thus, neither the short-term nor the long-term flight test programs hint that second-sourcing produces reliability sooner or affects the ultimate reliability.

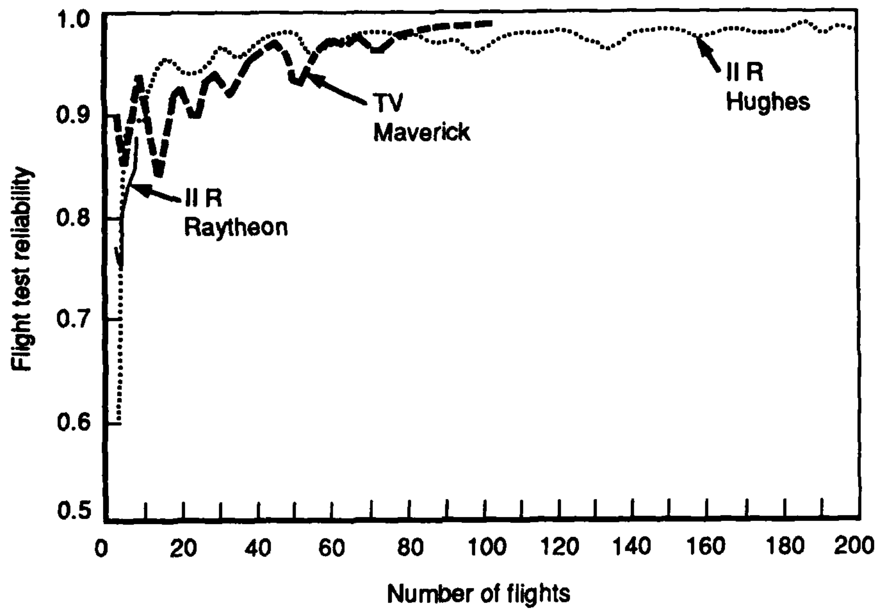


Fig. 16—Composite of long-term Maverick test results

Reliability figures on the ALCM, a single-source cruise missile, cannot be shown in this report. However, there were several failures in the first 15 flights, and the end-point reliability was low. The lower reliability of the ALCM and other cruise missiles relative to the much smaller Mavericks is not surprising, given their greater complexity and longer flight times. Tomahawk (GD/C) was somewhat unusual in that the first five flights were successful, then there were seven failures out of the next ten flights. The smoothed curve in Fig. 17 shows an end-point reliability of 72 percent. The MDAC Tomahawk had four failures out of the first 11 flights with the first two flights being unsuccessful. The reliability growth model tends to weight earlier failures less heavily than more recent failures, so that two programs with the same number of successes and failures but a different distribution will show slightly different values of end-point reliability.

Figure 18 displays Tomahawk (GD/C) long-term flight test reliability. Tomahawk with almost 180 flights to date has achieved a reliability level of about 97 percent, but it is different from the other missile systems examined in that flight-test reliability was not maintained at

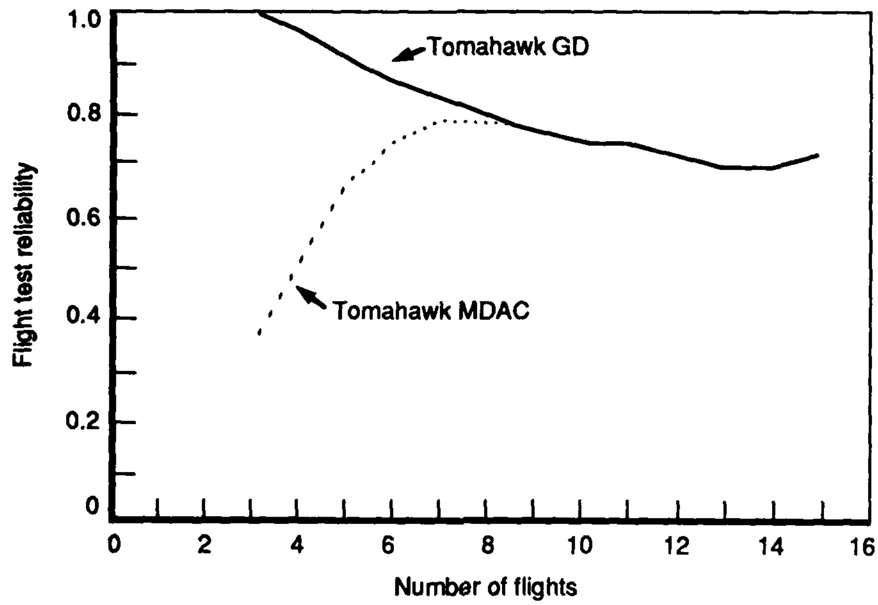


Fig. 17—Composite of cruise missile short-term test results

the 90 percent level until the 75th flight. The other missiles attained that level much earlier in their flight test histories, TV Maverick at test 6 and IIR Maverick at test 18.

When the history of Tomahawk flights 27 through 78 is compared with that of flights 80 through 177, the former set is found to have an average reliability of 87 percent and the latter, about 96 percent. The difference is statistically significant at the 95 percent confidence level; there is some reason, therefore, to believe that GD/C's effort to improve reliability began to show results at about the time of flight test 75, which occurred around March 1983. Events before that date that could have affected GD/C's attitude toward quality assurance were:

Jan 1981	CMP initiates dual-source effort
Nov 1981-May 1982	Five Method C corrective action requests issued
Mar 1982	Dual source contract awarded
Jun 1982	Method D corrective action issued
Mar 1983	Reliability improves.

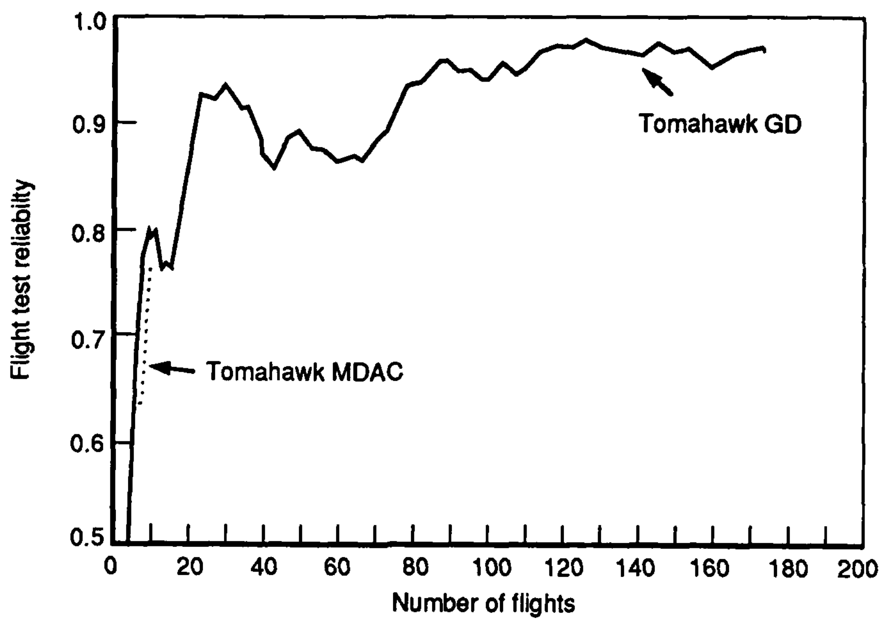


Fig. 18—Composite of cruise missile long-term test results

According to CMP and GD/C personnel, both second-sourcing and the corrective action requests were important. The proximate cause for action, however, appears to have been the DCASPRO letter of June 24, 1982, implying drastic action if "the Government's missile program is not measurably improved" in the next 120 days. During that grace period, GD/C formed a corporate team to identify and correct quality assurance problems, and three of the five Tomahawk flights between November 1982 and March 1983 were successful (one of the two failures was apparently related to the MDAC land-attack guidance system). Reliability improved steadily thereafter.

The problem all along, according to the CMP, was GD/C's disinclination to take the strenuous action required to correct engineering and manufacturing quality control problems. Imminent competition and the more direct corrective action requests both contributed to a change in corporate attitude. It would be mere speculation, however, to claim that one was more important than the other.

IX. CONCLUSION

There is no simple, foolproof method for determining whether second-sourcing will be or has been beneficial in any given planned defense procurement program. Early studies of second-sourcing indicated that net savings could be expected and that those savings could be expressed in percentage terms—e.g., a range of 12 to 78 percent with an average of 53 percent.[1] It was never clear, however, how a program manager should decide the percentage of net savings applicable to his program; and later studies showed that although savings were generally achieved, in the samples where it was tried, these samples also included programs that cost the government money.

More recently, the shift-and-rotation hypothesis has been advocated as a more rigorous method for predicting savings from second-sourcing. We object to automatic application of this method for several reasons. Competition can cause a downward shift in price, a rotation of the learning curve, or both; but neither is foreordained. Assumptions about shift and rotation should be based on an analysis of the price of early production items. Where the initial contractor is achieving a reasonable learning curve but the price seems too high, one might expect a healthy shift but no rotation. Where the contractor has predicted a flat learning curve, second-sourcing should produce a substantial rotation. Neither effect is guaranteed.

Where the merits of single- and second-sourcing have been weighed and the latter chosen, it is not surprising when after-the-fact studies substantiate that choice. We cannot disregard the other cases, however, where single-sourcing was chosen because of certain inherent advantages—lower investment cost, higher production rates, and greater production volume for a single contractor. Second-sourcing cannot overcome those advantages in every major procurement.

Dollar savings are not the only reason for bringing a second producer into a program. National security considerations may indicate having two producers for a system or subsystem, and second-sourcing is generally a satisfactory procedure for achieving that end. There are exceptions such as when a second source buys into a program, then drops out when it starts losing money. Competition may also drive marginal producers out of business. And the value of two prime

[1]Edward T. Lovett and Monte G. Norton, *Determining and Forecasting Savings from Competing Previously Sole Source/Noncompetitive Contracts*, APRO 709-3, Army Procurement Research Office, Fort Lee, Virginia, October 1978.

contractors may be illusory when they both rely on the same set of vendors for critical components.

Does second-sourcing result in a more reliable product? According to the Tomahawk project office, improved quality assurance, not cost reduction, was the primary reason for second-sourcing in the Tomahawk AUR program. There is little doubt that competition forces an attitudinal change on contractors who may have grown complacent in single-source production. When reliability is an important source-selection criterion, it has to be taken seriously. We cannot establish, however, that equipment produced in second-source programs has a superior reliability record.

In fact, an argument sometimes made is that reductions in hardware costs (e.g., the cost of a missile subsystem) can be offset by increases elsewhere (training, spares, field support, etc.). One of the easier ways to reduce hardware cost is to cut back the number of engineering and manufacturing support personnel assigned to a project. If the customer values the services those personnel have been providing, he can contract for them using support funds. Or equipment may require more support in the field because of economies in production. We have no evidence that reductions in support labor result in cost increases elsewhere either immediately or after a weapon is in the field, but for every product there is a fair price. If competition causes a contractor to bid a price below that level, something is likely to suffer.

Lower cost, greater reliability, alternative production sources—these are good reasons for second-sourcing but not necessarily the real reason. In some instances the underlying reason has been a profound dissatisfaction with the behavior of the initial contractor. The defense procurement system is such that once a contractor is chosen to develop a new system the responsible military service is locked in a relationship with that contractor that could last for 20 years or more. Bringing a second company into a program is a convenient way to encourage greater cooperation and responsiveness from the initial firm.

Whatever the real reason for second-sourcing may be, it is most commonly justified on the basis of lower cost. In most cases where it is chosen, competition does result in lower recurring costs. The question is whether the planned production quantity is sufficient that the savings in recurring costs will offset the incremental startup costs of second-sourcing. That question is made more difficult by the fact that planned production quantities change over the course of system development and production. The number may increase, as in the Tomahawk case, and make second-sourcing a better bet; but the number often decreases. A frequently cited example is that of the Navy's plan to establish Pratt & Whittney as a second source to

General Electric for the production of F404 jet engines for the F/A-18 fighter aircraft. After spending about $300 million to establish Pratt & Whitney as a competitor, the Navy ordered only about 200 engines from that firm and ended the competition.[2] In other cases contractors have invested in new facilities to handle expanded production only to see orders cut back to a fraction of the quantities projected earlier by the military services. Instead of greater efficiency a firm is faced with the need to allocate higher fixed costs over a smaller production base.

In a period of declining defense budgets, savings from second-sourcing will be more difficult to achieve. Contractors do respond to competition, but the timing and nature of their responses vary from program to program. The Tomahawk AUR program provides a good example of the specific factors needed for successful second-sourcing. First, the cost of entry for a second producer was low—less than 2 percent of the projected cost of over 4000 units. Second, the original airframe producer projected a fairly flat learning curve in its own studies. It was not hard to forecast savings when single-source target prices were established at that level. Virtually every other missile program had achieved a steeper slope. Third, annual production quantities were large enough to absorb the fixed and semi-fixed costs without distorting AUR unit costs unduly. Fourth, the total planned production quantity was large enough that breakeven was virtually guaranteed.

A variety of analytical techniques may be useful in evaluating potential savings from second-sourcing—estimating dollar savings directly, determining the breakeven quantity, solving for the shift and/or rotation required to breakeven at the planned quantity, etc. We do not advocate any particular method here; we are concerned only that analysts use all the information available to them, including historical data for comparable equipment, and that they do not rely on an ideological commitment to competition for an answer.

[2]David C. Morison, "Two for the Money," *National Journal*, June 2, 1990.